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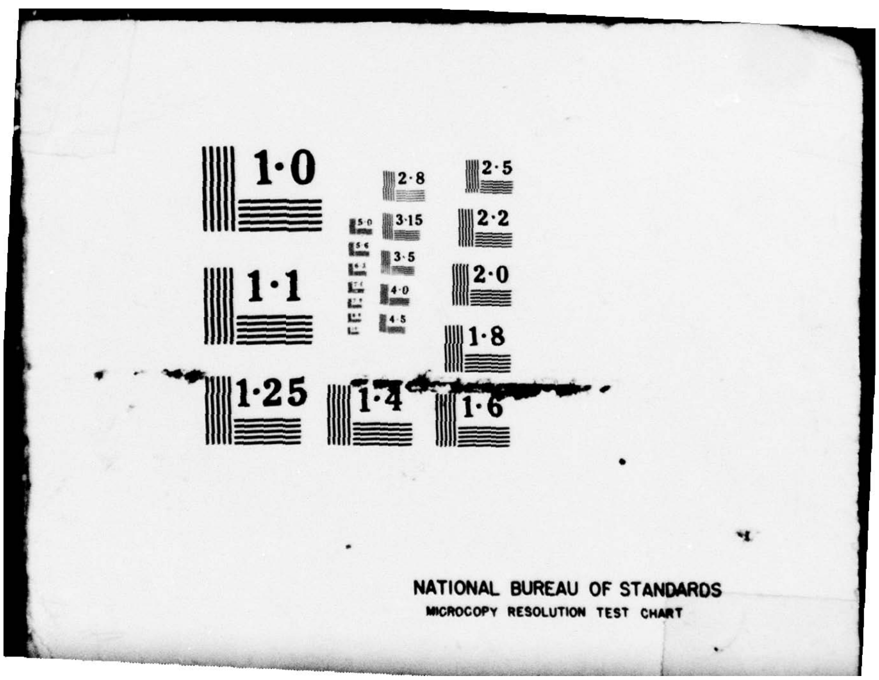
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PROGRAM DEVELOPMENT TO STUDY FAIRED TOWLINES

J. B. Eades, Jr.
V. Majer

BUSINESS AND TECHNOLOGICAL SYSTEMS, INC.
Seabrook, Maryland 20801

Contract No. N00014-78-C-0410
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January 1979

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A COMPUTER PROGRAM HAS BEEN DEVELOPED TO STUDY THE INTERACTIONS BETWEEN HYDRODYNAMIC LOADING AND STRUCTRUAL RESPONSE OF FLEXIBLE, FAIRED, UNDER-WATER TOWING CABLES. THE EQUILIBRIUM SHAPE OF THE CABLE'S CROSS-SECTION WHEN IT IS MOVING AT AN ANGLE OF ATTACK IN A STEADY TWO-DIMENSIONAL VISCOUS FLOW (FIELD) IS COMPUTED.

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THE COMPUTATIONAL ALGORITHMS HAVE BEEN ARRANGED SO THAT THE USER CAN COMPUTE EITHER THE POTENTIAL OR POTENTIAL-VISCOUS PRESSURE DISTRIBUTION, OVER THE SHAPE, AND DETERMINE THE ATTENDANT TWO-DIMENSIONAL HYDRODYNAMIC FORCE AND MOMENT COEFFICIENTS. THIS PRESSURE LOADING IS NEXT APPLIED TO THE ELASTIC CROSS-SECTION (OF THE SHAPE) AND A STRUCTURAL RESPONSE (DEFLECTED SHAPE) IS COMPUTED. (THE METHOD USED FOR THIS PURPOSE IS A FINITE ELEMENT APPROACH; THE PROBLEM IS TREATED AS A NON-LINEAR SITUATION WHEREIN LARGE DEFLECTIONS AND/OR NON-LINEAR ELASTIC PROPERTIES MAY BE ENCOUNTERED.) THIS PROCESS IS REPEATED UNTIL EQUILIBRIUM BETWEEN INDUCED PRESSURE AND DEFORMED SHAPE IS ATTAINED.

THIS PROGRAM WAS DEVELOPED TO STUDY CLASSES OF FAIRED UNDERWATER TOWING CABLES WHEREIN THE FAIRING IS RUBBER (OR OTHER ELASTIC) COMPOSITION, BONDED TO A STRENGTH MEMBER, ALL OF WHICH MAY BE ENCASED IN A BONDED FILM-LIKE COVERING.

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1. INTRODUCTION

An increasing interest in high speed towlines and towed devices by the naval establishment has led to the development of low drag, faired (streamlined) towing systems. It is clearly important that these, like all other towing cables, must maintain a specific and predictable orientation throughout their operational speed ranges.

Unfortunately, some faired cables that have been put into service have exhibited dynamic instabilities. In particular, they have experienced a lateral instability which is commonly referred to as "kiting". Although steps to correct kiting have been taken in the field, based on "engineering intuition" and experience, it is more desirable to do so using knowledge gained from studying the interactions between hydrodynamic loading and structural properties of such faired cables. Additionally, such a study might lead to an optimized design for future faired cable systems (optimized with respect to load carrying characteristics and predictable dynamics).

In this report we will document the development of a computer program designed to study precisely those hydrodynamic/structural interactions which contribute to the "kiting" of faired towlines. Briefly, the present effort has been directed to coupling a collection of algorithms which predict the hydrodynamic loads -- *on a fairing* cross-section of given shape -- to a collection of algorithms which describe the fairing's (structural) response to the imposed loading. Naturally, since the fairing responds to loads by deforming, and since the fairing's shape in turn determines the hydrodynamic loads, an equilibrium state is achieved only after several "iterations" through this process. Since one segment of the program computes the HYDROdynamic loads whose effects on the fairing are determined by the nonlinear Structural Analysis Program segment, we have (not without certain misgivings) called the full program HYDROSAP.

The report is organized as follows: In section 2 we discuss the overall organization of HYDROSAP. Particular attention is given to describing the interface and auxiliary software necessary to effectively control all the

operations of the program's hydrodynamic and structural response modules. The program's input requirements are explained in section 2.4. In section 3 we discuss, in detail, the hydrodynamic computations and the attendant (optional) input requirements. A parallel discussion for the structural response computations appears in section 4. Section 5 is devoted to the description and discussion of a sample HYDROSAP analysis. In the several appendices, attached hereto, we give details of the program's structure and describe the job control language (JCL) needed to operate the program on the IBM 360/91 system at the Goddard Space Flight Center.

2. DESCRIPTION OF THE HYDROSAP SYSTEM

2.1 Overview

The HYDROSAP program has been built to study the nonlinear interaction of hydrodynamic and structural effects on an elastic two-dimensional fairing (cross-section) exposed to a steady field of fluid flow. In order to achieve this objective elements from two existing computer programs, the NASA Multi-component Two-dimensional Viscous Airfoil Program (herein dubbed HYDRO) and the University of California Nonlinear Structural Analysis Program (NONSAP), were integrated into a single software system.

The integrated system determines an equilibrium shape for a flexible fairing exposed to the hydrodynamic loading developed by moving the fairing through a steady state stream. The equilibrium shape is determined by passing successively through the HYDRO and NONSAP modules until the change in fairing geometry, between successive passes, is smaller than some pre-set error tolerance. This iterative computational procedure is depicted pictorially in Figure 2-1.

In order to control the transfer of data from one program module to the other, a collection of auxiliary software was designed and coded. These auxiliary routines perform pre- and post-processing operations for both modules. They also provide for the interfacing between modules. In addition to the above, the HYDROSAP package includes several features which make the program quite versatile, but yet easily accessible to (even) the inexperienced user:

(1) HYDROSAP has three basic modes of operation. Besides operating in the "full" HYDROSAP iteration mode, the user is able to run the HYDRO or NONSAP modules individually. By judiciously overlaying (see Appendix A) each of the program modules, and by a careful design of the auxiliary interface routines, this capability has been retained with little increase in core requirements over a

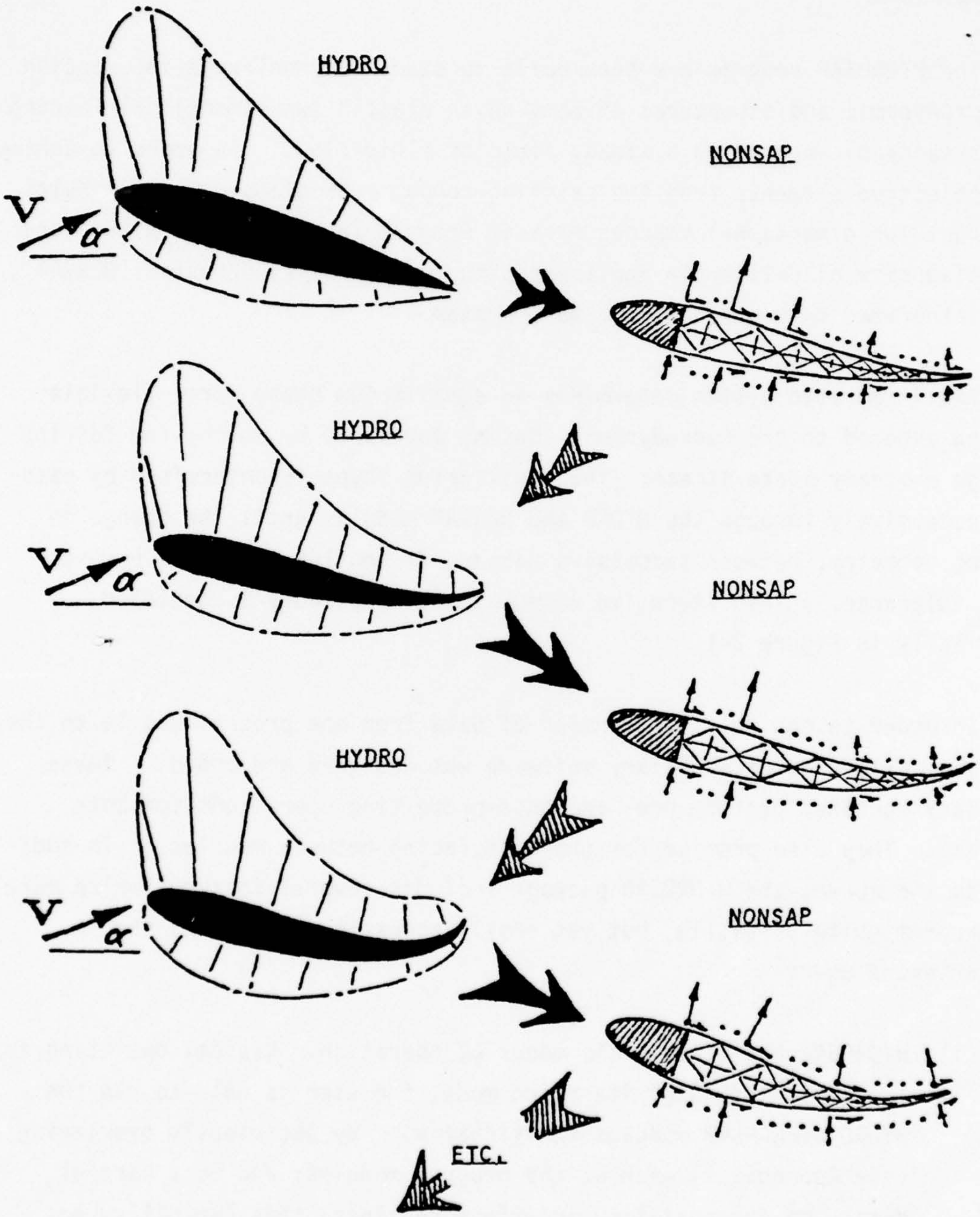


Figure 2-1. Schematic depicting the iterative operations of HYDROSAP -- a hydrodynamic loading, structural response software system.

reduced version of HYDROSAP using a "gutted" form of the HYDRO and NONSAP modules.

(2) The various HYDROSAP options and features are activated by means of a simple NAMELIST input. This form of input frees the user from the error-prone and tiresome preparation of formatted input decks. Moreover, it provides a simple and effective way to set default values for control variables.

(3) An especially attractive HYDROSAP feature is the "short form" input pre-processor. Both the HYDRO program and the NONSAP program require rather large and complicated formatted input decks. If the user selects the built-in short form input pre-processor, these input decks are constructed automatically, based on the values of several namelist control variables, and on certain assumptions about the class of symmetric fairing cross-sections to be studied. Of course, the user may elect to provide complete HYDRO and NONSAP decks himself. In this case, the fairing's cross-section (geometry) and elastic and construction details can be completely arbitrary. Whatever the origins of the input decks, however, the user may produce an "echo" of the input deck card images on the output unit. This feature facilitates the "debugging" and checking of input.

(4) Also, the user may obtain a summary of the job flow at his remote terminal. "Milestone" messages mark the beginning and ending of each stage of the computation; and, convergence messages give the "size" of the displacement error (from equilibrium) relative to a user-assigned convergence tolerance. Also, any program-generated error messages appear at the terminal, as output, in addition to appearing on the main printer output.

(5) A convenient checkpoint/restart capability is also available to HYDROSAP. Should a run terminate abnormally (e.g., the computation time might exceed the time estimate on the job card) the user

may restart and continue the computation from the last stored checkpoint. This procedure represents a savings, in time and costs, since the sequence of expensive computations completed before cut-off need not be repeated.

(6) Finally, data necessary to produce graphs of the pressure distribution or the deformed foil's shape, after each HYDROSAP iteration, may be directed to disc or tape storage for subsequent retrieval by the BTS-developed plotting program HSGRAF.

2.2 HYDROSAP Organization

In this section, we describe the organization of the HYDROSAP system and the role of the auxiliary software (Figure 2-2).

The HYDROSAP computation begins (BEGINØ) with the setting of default values for the control variables in NAMELIST /DRV/. INPUTØ reads Tape 5 to ascertain over-ride control variable values prescribed for the run by the user. A detailed explanation of the control variables is given in section 2.4.2 below.

If the user has selected short form input pre-processing, subroutines HYDIN and SAPIN are called to construct, respectively, the HYDRO (Tape 55) and NONSAP (Tape 66) input files. The fairing cross-section (profile) is supplied either from a collection of profile library subroutines (FOILØ1, FOILØ2,···etc.) by DEFALT, or from the input stream through NAMELIST /FAIRNG/. Note that only the fairing's upper surface profile need be provided, since HYDIN and SAPIN assume a symmetric fairing. Control variables from NAMELIST /DRV/ define the problem's operating conditions (angle of attack, static pressure, and freestream velocity).

Next, SAPIN generates the finite element mesh for NONSAP based on the upper surface profile geometry and on values of the control variables which define the mesh "fineness", and the materials composition for the fairing.

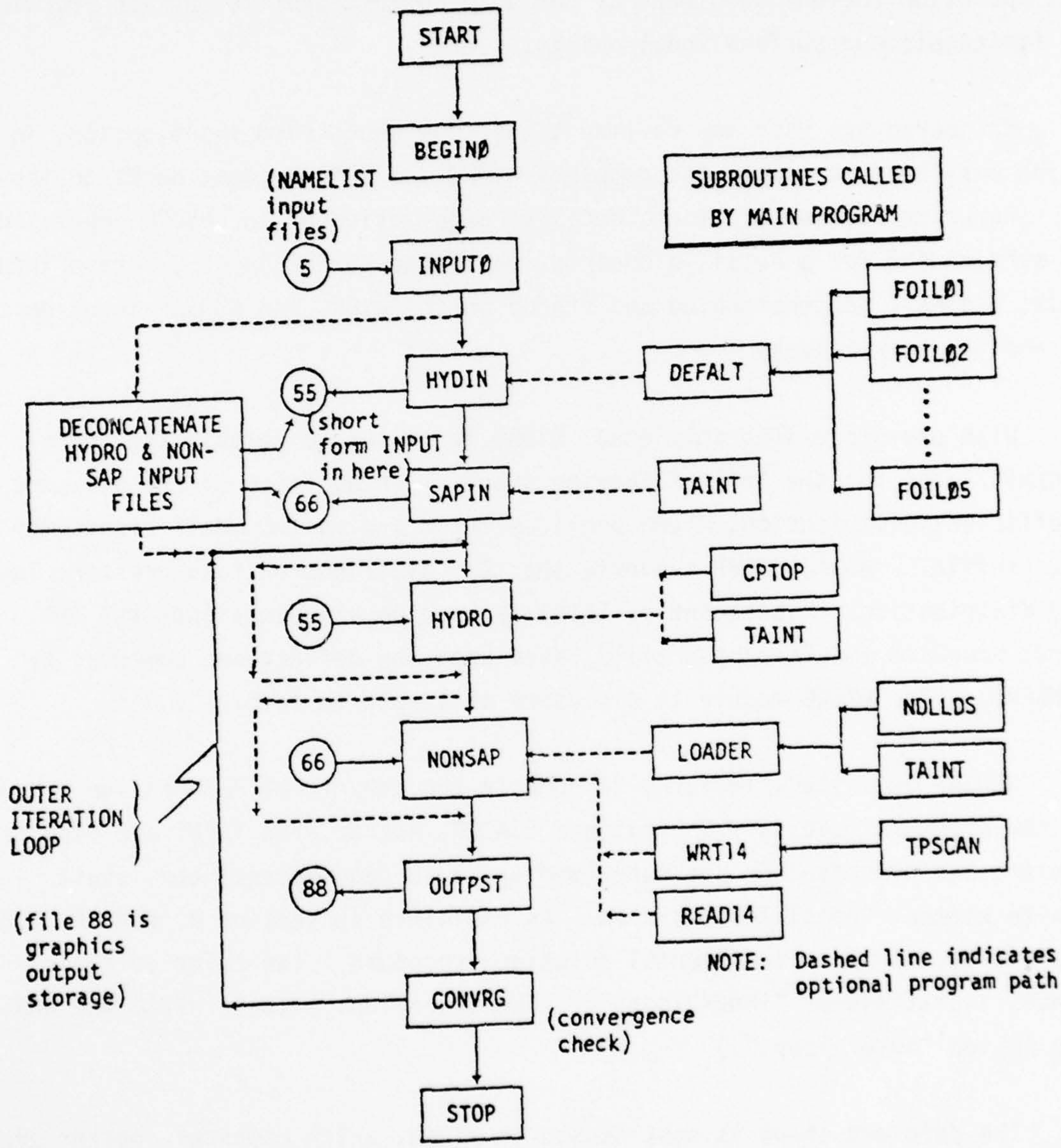


Figure 2-2. HYDROSAP ORGANIZATION (and Computational Path-Flow Diagram)

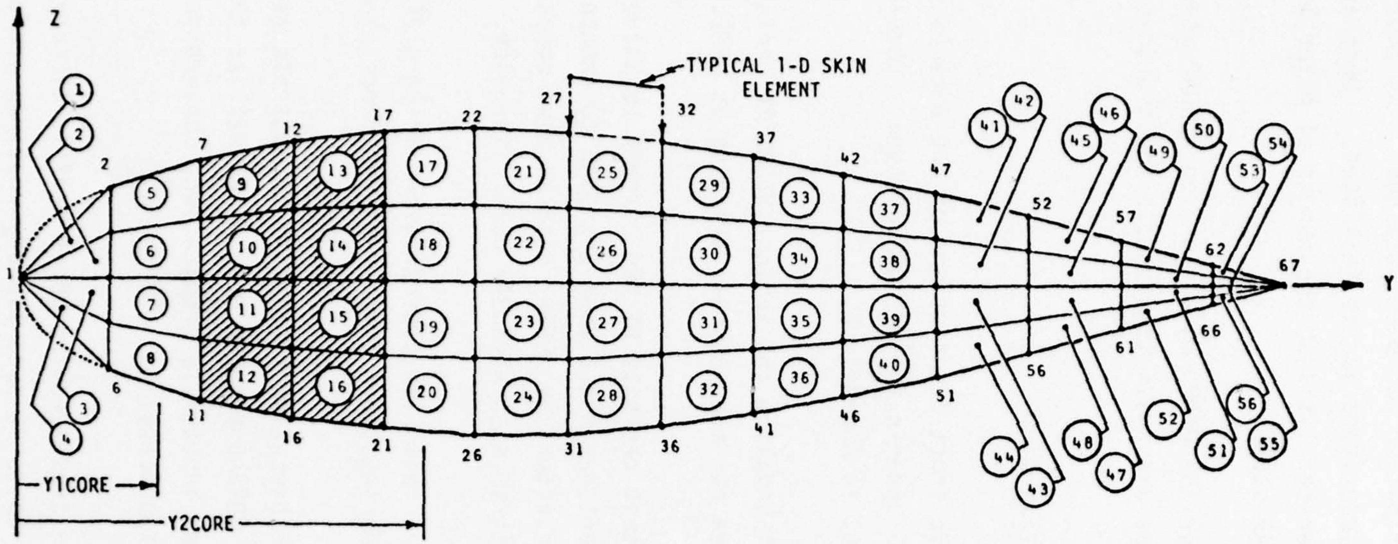
In using the short form input, the fairing is assumed to consist of one or more of the following parts: a cable core (strength member), a fairing tail (afterbody), and/or an enclosing skin. Figure 2-3 shows an example of a finite element mesh as generated by SAPIN. TAINT is a table lookup and interpolation routine used here by SAPIN to convert profile surface coordinates to finite element surface nodal points.

Of course the user may decline to use the short form input option, in which case he must supply the complete HYDRO and NONSAP input decks on Tape 5. (Refer to section 3.3 for a detailed description of the HYDRO input, and to section 4.3 for a detailed description of the NONSAP input.) These input decks are next deconcatenated and stored on the HYDRO and NONSAP input units, 55 and 66, respectively.

With pre-processing completed, HYDRO is called to compute the hydrodynamic loads for the initial fairing shape. In addition to the pressure coefficient distribution, HYDRO provides force and moment coefficients for the profile. Next, CPTOP converts the C_p distribution to a pressure loading distribution. Subsequently, TAINT is used on all iterations but the first to update the fairing profile based upon the deflections computed by NONSAP. (The HYDRO module is discussed at length in section 3.)

NONSAP is called, in turn, to compute the structural deformation induced by the pressure loading. Subroutines LOADER, NDLLDS, and TAINT are used to convert the hydrodynamic pressure loading to an (equivalent) consistent finite element "nodal-load" system. As explained in section 4, NONSAP itself employs an iterative incremental solution procedure. (We refer to these NONSAP iterations as "inner loops". The iterations between HYDRO and NONSAP are called "outer loops".)

The deformed shape is next passed to HYDRO, which computes another pressure distribution based upon the new shape. If the user desires, data for graphics post-processing can be stored on Tape 88. Another program, HSGRAF, is available to produce graphs of the pressure or deformed shape profiles.



NOTES:

(1) MESHC=13, MESHT=3

(2) SHADED Elements assigned material properties of the core.

(3) NON-SHADED Elements assigned material properties of the TAIL

(4) (x) = element number

• = node (number)

(5) Nodes numbered, sequentially, in vertical direction.

Figure 2-3. Cable Fairing Cross-Section Finite Element Mesh, as Generated by HYDROSAP Short Form Input Pre-processor

At the end of each outer loop, CONVRG is called to determine whether an equilibrium shape/pressure distribution has been obtained. If equilibrium is not achieved, another outer loop iteration is initiated. Once an equilibrium state is achieved, or a user-set limit on the number of outer loop iterations has been exceeded, HYDROSAP stops.

Finally, we note that either the HYDRO module or the NONSAP module can be completely bypassed should the user wish to uncouple the hydrodynamic and structural computations.

2.3 Interface and Auxiliary Software

In this section we will give short descriptions of the various auxiliary and interface routines which are used in the HYDROSAP system. Complete subroutine descriptions are provided in Appendix B.

BEGINØ — A subroutine to initialize the various HYDROSAP variables and set default values for the control variables in NAMELIST /DRV/.

CONVRG — An algorithm to test the size of the current relative displacement increment against a user-assigned tolerance. This routine is called after the NONSAP displacement computations are completed, within each HYDROSAP outer iteration.

DEFALT — A subroutine which calls the appropriate fairing profile library routine during short form input pre-processing.

DRIVER — The main HYDROSAP executive routine. It controls execution of the HYDRO and NONSAP program modules as well as the initialization procedure, input file preparation, convergence testing, and graphics post-processing.

FOILnm — This is a fairing cross-section upper profile library routine numbered "nm". Up to 99 such library routines are possible within HYDROSAP. These routines provide default surface coordinates for short form input. Currently nm ranges from Ø1 to Ø5 as follows:

FOILØ1 A typical fairing profile measured from a sample of a DTNSRDC cable section.

FOILØ2 Fairing Model I taken from DTNSRDC Report 461Ø.

FOILØ3 An NACA ØØ2Ø profile.

FOILØ4 An NCS ØØ1Ø profile.

FOILØ5 A subroutine reserved for future expansion.

HYDIN This routine builds a complete HYDRO input file based upon values of the control variables read from NAMELIST /DRV/ during short form input pre-processing.

INPUTØ A routine which over-rides the default values of the HYDROSAP control variables with values read from NAMELIST /DRV/.

OUTPST This subroutine writes the pressure distribution and deformed shape data to output Tape 88.

SAPIN The routine which builds a complete NONSAP input file based upon values of the control variables from NAMELIST /DRV/ during short form input pre-processing.

TAINT This is a general purpose "table lookup and interpolation" algorithm.

LOADER An algorithm to control the computation of consistent nodal loads which are to be applied at the NONSAP fairing surface nodes, based on the computed pressure distribution from HYDRO.

NDLLDS This subroutine determines the consistent nodal loads using the fairing's surface geometry and pressure distribution.

CPTOP An algorithm which converts non-dimensional surface pressure coefficients to surface pressures.

WRT14 This subroutine writes the HYDROSAP checkpoint/restart tape,

Tape 14. WRT14 uses TPSCAN to scan the four NONSAP restart tapes to determine the number and size (in bytes) of each tape's records. HYDRO restart data is concatenated with the four NAPSAP restart tapes to form each HYDROSAP checkpoint on a single unit, Tape 14.

TPSCAN — This subroutine scans a file written with unformatted FORTRAN WRITE statements to determine the length (in bytes) of each record and the total number of records.

READ14 — A routine which reads and unloads the checkpoint/restart tape, Tape 14.

2.4 HYDROSAP Input

2.4.1 Input Stream Format

The HYDROSAP input cards are identified with Tape 5 (usually the system input stream). The input stream consists of six distinct card groups, not all of which are present in a single run. Only the first two card groups must be present; the presence or absence of the other four groups is determined from values assigned by the user to the NONSAP control variables SHRTIN, HYDSIM, SAPSIM, and N. All of the control variables are defined in section 2.4.2, below. The input stream card groups are as follows:

CARD GROUP 1 — Title Card

Card 1.1 — Title of Run
1
Up to an 80 character title for the run.
(This card must appear.)

CARD GROUP 2 — Control Variables

Card 2.1 — $DRV
12
Header card for NAMELIST /DRV/; signals the beginning of the control input. (This card must appear.)

```
Card 2.2        __SHRTIN=T,···
                123
    :           Input as many cards as required to override default control
                variable values.
Card 2.n
Card 2.n+1      _$END
                12
                End card for NAMELIST /DRV/;  signals the termination of
                the namelist string.  (This card must appear.)

CARD GROUP 3    Cable Fairing Profile Namelist (optional)
                Card Group 3 is present only if SHRTIN=T and N>0 in
                NAMELIST /DRV/.
Card 3.1        _$FAIRNG
                12
                Header card for NAMELIST /FAIRNG/.
Card 3.2        __XX(1)=···,XX(N)=···,
                123
    :
Card 3.m        __ZZ(1)=···,ZZ(N)=···,
                123
                {(XX(I),ZZ(I)), I=1,···N} are the profile coordinates, in
                inches, for the upper surface of the symmetric cable fair-
                ing to be modeled.   N is set in NAMELIST /DRV/.
Card 5.m+1      _$END
                12
                End card for NAMELIST /FAIRNG/.

CARD GROUP 4    HYDRO Input Deck (optional)
                Card Group 4 is present only if SHRTIN=F and SAPSIM=F in
                NAMELIST /DRV/.
Card 4.1        First card of HYDRO input deck
    :               : } see section 3.3
Card 4.p        Last card of HYDRO input deck.
```

CARD GROUP 5		Spacer
	Card 5.1	99999999 12345678 A spacer card to be inserted between HYDRO and NONSAP input decks. (This card must be present whenever SHRTIN=F.)
CARD GROUP 6		NONSAP Input Deck (optional) Card Group 6 is present only if SHRTIN=F and HYDSIM=F in NAMELIST /DRV/.
	Card 6.1	First card of the NONSAP input deck.
	⋮	⋮ } see section 4.3
	Card 6.q	Last card of the NONSAP input deck.

2.4.2 Control Variable Definitions

The HYDROSAP Control Variables (Card Group 2 of the HYDROSAP Input) fall into two groups: logical variables and arithmetic variables. The logical variables are true/false switches used to activate the various program options. The arithmetic variables are used to set values for the integer and real variables which control the flow of computations (examples are: iteration counters, output units, mesh fineness, and convergence tolerance), or define the physical parameters of the problem under study (such as flow conditions and material properties). Detail definitions of the control variables are as follows:

VARIABLE	TYPE	DEFAULT	INTERPRETATION	
CHKPNT (CHecKPoiNT)	LOGICAL	.FALSE.	=.TRUE.	Produce checkpoint tape (FT14FØØ1)
			=.FALSE.	Checkpointing disabled.
CORE	LOGICAL	.FALSE.	=.TRUE.	Fairing has a cable (core) material
			=.FALSE.	No distinct cable (core) present
			(SHRTIN=.TRUE. only)	

VARIABLE	TYPE	DEFAULT		INTERPRETATION
DEBUG	LOGICAL	.FALSE.	=.TRUE.	Special print in LOADER: HYDRO and NONSAP output provided at each HS iteration (iteration = outer loop)
			=.FALSE.	HS print produced at start of run only. <u>No debug output</u>.
ECHO	LOGICAL	.TRUE.	=.TRUE.	Echo of HYDRO and NONSAP input decks produced.
			=.FALSE.	Suppress "echo" of files.
HYDSIM (HYDro SIMulation)	LOGICAL	.FALSE.	=.TRUE.	Program operates in the HYDRO simulation mode (SAPSIM <u>must be</u> .FALSE.)
			=.FALSE.	Signifies a request for the full HYDROSAP run; or NONSAP simulation, depending on the value assigned to SAPSIM.
POST	LOGICAL	.FALSE.	=.TRUE.	The Graphics Post-processor output is directed to Unit 88.
			=.FALSE.	No operation requested.
RESTRT	LOGICAL	.FALSE.	=.TRUE.	Read checkpoint tape and restart at time TSTART
			=.FALSE.	Restart disabled.
SAPSIM	LOGICAL	.FALSE.	=.TRUE.	Program is to operate in NONSAP simulation mode (HYDSIM <u>must be</u> set to .FALSE.)
			=.FALSE.	Full HYDROSAP run; or HYDRO simulation, depending upon value assigned to HYDSIM.

VARIABLE	TYPE	DEFAULT		INTERPRETATION
SHRTIN (SHoRT form INput)	LOGICAL	.TRUE.	=.TRUE.	Signifies the short form input. An automatic input file generation occurs (for foil geometry and state).
			=.FALSE.	HYDRO and NONSAP input decks, separated by 999999999, must follow $DRV-$END on SYSIN file.
SKIN	LOGICAL	.FALSE.	=.TRUE.	Denotes the fairing cross-section has a skin attached.
			=.FALSE.	No skin member is presumed.
TAIL	LOGICAL	.TRUE.	=.TRUE.	The fairing has a fairing "tail" member.
			=.FALSE.	No fairing tail is assumed (CORE must be set to .TRUE. in this case).
TPRINT (Terminal PRINT)	LOGICAL	.TRUE.	=.TRUE.	Terminal summary output (error msgs. and job flow)
			=.FALSE.	No terminal print.
INTORD (INTerpolation ORDer)	INTEGER	3	Denotes the interpolation order for the pressure distribution conversion from the HYDRO surface to the NONSAP surface.	
INTORX (INTerpolation ORder X)	INTEGER	1	Interpolation order to be assigned for the displacement conversion from the NONSAP surface to the HYDRO surface.	
IPANEL	INTEGER	2	IPANEL is equivalent to HYDRO control variable IOP.	
IPAPER	INTEGER	6	Unit number assigned to the HYDROSAP DRIVER module output.	

VARIABLE	TYPE	DEFAULT	INTERPRETATION
IPRINT	INTEGER	=NSTEPS	Denotes the NONSAP print frequency within HYDROSAP ITERATION #1.
ISMTH	INTEGER	0	ISMTH is equivalent to HYDRO control variable ISMO.
ITRSWT (ITeRation SWiTch)	INTEGER	8	The number of HYDROSAP iterations using HYDRO potential flow solution mode only.
IWRTØ	INTEGER	6	Denotes the NONSAP output UNIT.
IWRT1	INTEGER	6	Denotes the HYDRO output unit.
LOOPMX (LOOPMaXimum)	INTEGER	1	Signifies the maximum number of HYDROSAP iterations (outer loops) allowed.
MESHC (MESHChordwise)	INTEGER	1	Denotes the number of chordwise interior stations used to generate the finite element mesh, when SHRTIN is set to .TRUE.
MESHT (MESHThickness-wise)	INTEGER	1	Denotes the number of lateral interior stations used to generate the finite element mesh when SHRTIN is set to .TRUE.
N	INTEGER	Ø	N>Ø Signifies the number of upper surface coordinate pairs to be input through NAMELIST $FAIRNG-$END, following NAMELIST $DRV-$END, on SYSIN. N=Ø Means no fairing profile is input. N<Ø A pointer for profile library routine |N|. Thus, N= -2 reads profile points from subroutine FOILØ2. (Applicable when SHRTIN set to .TRUE., only.)

VARIABLE	TYPE	DEFAULT	INTERPRETATION
NSTEPS	INTEGER	2Ø	Denotes the number of (quasi-static) load steps to be used in applying the field pressure load to a fairing, in NONSAP, during HYDROSAP iteration #1.

Note: NSTEPS should be increased when the message "OUT-OF-BALANCE LOADS EXCEED INCREMENTAL LOADS" is obtained.

VARIABLE	TYPE	DEFAULT	INTERPRETATION
ALPHA	REAL*8	Ø.DØ	Angle of attack (deg.)
ECORE	REAL*8	1.DØ6	Young's modulus for the core material (psi).
ESKIN	REAL*8	1.DØ4	Young's modulus for the skin material (psi).
ETAIL	REAL*8	1.DØ4	Young's modulus for the fairing tail material (psi).
PCORE PSKIN PTAIL	REAL*8	.3 Ø .3	Poisson ratio for the core, skin, and tail, respectively.
PZERO	REAL*8	14.7DØ	Static pressure loading (psi).
RHO	REAL*8	2.DØ	H_2O density (slugs/ft^3).
TOL	REAL*8	$1\times1Ø^{-2}$	Denotes the HYDROSAP convergence tolerance level. Convergence is achieved when rms displacement increment <(rms displacement) * TOL.
TSKIN	REAL*8	.ØØ5	Skin thickness (inches) (applies only if SKIN is set to .TRUE.).
TSTART (Time of reSTART)	LOGICAL	Ø.DØ	Applies only when RESTRT= .TRUE. HYDROSAP will restart at checkpoint for time TSTART.
VFRSTR	REAL*8	22.DØ	Free stream velocity (fps).
Y1CORE	REAL*8	Ø.DØ	Chordwise location of the core starting point.
Y2CORE	REAL*8	Ø.DØ	Chordwise location of the core ending point.

2.5 HYDROSAP Output

The output for the entire HYDROSAP program can be divided into four groups: HYDROSAP printer output, HYDROSAP terminal summary output, HYDRO module output, and NONSAP module output. The user may control the presence of these output forms through the HYDROSAP control variables IPAPER, IWRTØ, IWRT1, and TPRINT, as discussed in section 3.4 and section 4.4 below. In this section we will briefly discuss the HYDROSAP printer and terminal output.

2.5.1 HYDROSAP Printer Output

HYDROSAP printer output appears on unit IPAPER (usually unit 6). Basically it contains a listing of program control information, convergence data regarding the HYDRO-NONSAP iterations, for "full" HYDROSAP runs, and any error messages which may occur.

Immediately following the banner title is an echo of the values of the entire control variable namelist, /DRV/. If the user has set ECHO=T, the next data appearing on the printer listing is an echo of the HYDRO and/or NONSAP input deck card images. The echo is preceded by the message

ECHO OF INPUT DECK FOR HYDRO AND NONSAP SUBPROGRAMS ,

and followed by the message

END ECHO .

The HYDRO and NONSAP decks are separated by the notation

--END HYDRO INPUT; BEGIN NONSAP INPUT-- .

Following the input stream echo on unit IPAPER are messages marking the beginning of each outer iteration. The usual practice is to direct HYDRO and NONSAP output to the printer as well (IWRT1=IWRTØ=IPAPER=6), thus the results

of the hydrodynamic and structural deformation computations appear in sequence for each HYDROSAP outer iteration.

Following the HYDRO and NONSAP output for each iteration is a message from subroutine CONVRG. The current relative displacement error, RATIO, and the user's input convergence tolerance, TOL, are listed. ISTOP equals zero until RATIO$\leq$TOL, in which case ISTOP is set to 1 and the computations are terminated. The computations also terminate if the iteration counter, ITER, exceeds the user-set maximum, LOOPMX. The displacement increment and total displacement for each degree of freedom are listed in compacted form in order of equation number. Finally, the output ends with an informative message explaining how the computation terminated.

2.5.2 HYDROSAP Terminal Summary Output

Terminal summary output appears on unit 12 if TPRINT=T. A sample of terminal summary output is given in Figure 2-4. The user is informed as the HYDRO and NONSAP modules are accessed during each HYDROSAP outer iteration. The results of the convergence check, at each outer iteration, are also given; and, a final message informs the user of the run's method of termination. Under abnormal circumstances any error messages generated by the program are reproduced here also.

```
COMMENCE HYDROSAP EXECUTION
*** ITERATION  1 ***
BEGIN  HYDRO PHASE
END    HYDRO PHASE
BEGIN NONSAP PHASE
END   NONSAP PHASE
ERROR =  1.0000D 00, W.R.T. UNITY =  1.0000D 03, NOT CONVERGED
*** ITERATION  2 ***
BEGIN  HYDRO PHASE
END    HYDRO PHASE
BEGIN NONSAP PHASE
END   NONSAP PHASE
ERROR =  8.5004D-05, W.R.T. UNITY =  8.5004D-02,     CONVERGED
RUN TERMINATED BECAUSE CONVERGENCE ACHIEVED
```

Figure 2-4. Sample of Terminal Print Summary

3. DESCRIPTION OF HYDRO - THE VISCOUS/POTENTIAL FLOW SUBPROGRAM

This component of HYDROSAP is the program segment used to describe the hydrodynamic loads which are applied to a streamlined fairing's cross-section. The particular collection of algorithms and subroutines, found here, have evolved from the systems described in [1,2],* and provide a basis for the system described in [2]. The utility of this program segment has been alluded to earlier; therefore, the present section of the documentation has been prepared to provide the reader with a general understanding of the program's operation, its attributes and its general limitations.

Included in the following paragraphs is an overview and description of HYDRO; a short description of the subroutines, etc. comprising the system; and a brief discussion on the input format required to run the program. Should the reader desire a more detailed discussion and description of the theory, etc., used in building the system, the references (included herein) should be consulted (especially [1], [2], [3] and [4]).

3.1 Program Description

The "hydrodynamic loading" program, which has been given the name HYDRO, here, is constructed in four segments. Each of these subsystems plays a distinct computational role in developing the foil's pressure distribution, and in the generation of force and moment coefficients which characterize the fairing section. A descriptive flow chart for this program is given on Figure 3.1.

The principal program segments here are (each) controlled by one of the following subroutines: AIRGM, POTFL, BDLYR and LOADSØ. In the next few paragraphs a word description of their operation and function will be given. Needless to say, there is one overriding (executive) routine, in the program's hierarchy, which has the function of initiating, maintaining and executing control over the entire subsystem. This routine has been (appropriately) dubbed, HYDRO.

*Numbers appearing in [ ] denote references.

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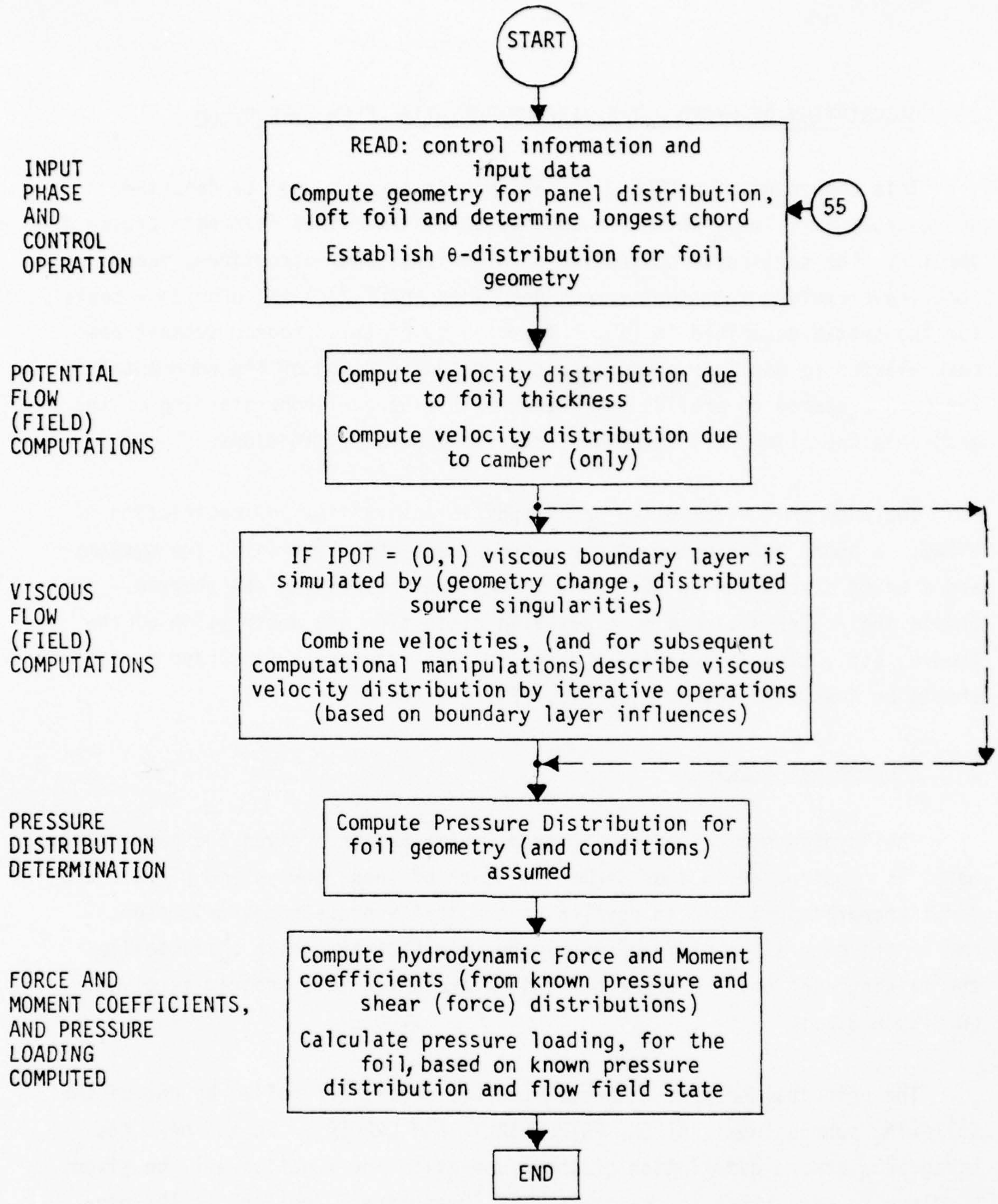

Figure 3.1. HYDRO Flowchart. Program Operation for Single Element Streamlined Foil

3.1.1 The Foil Geometry Section

The AIRGM segment is responsible for reading in the input data, performing the various geometry chores needed in setting up a problem, and establishing the various geometric relationships required in the subsequent analysis. One of the major chores performed by this routine is the distribution of (geometry) "panels" needed for the pressure distribution calculations. In this regard the system has three options available internally; the choice of option is user controlled through the input stream. The default option (presently available) is a distribution of "panels" according to the degree of local surface curvature.

The various subroutines making up the AIRGM segment of this program can be seen on the HYDRO structure map in Appendix A.

3.1.2 The Potential Flow Field Section

The next segment called is that which computes the potential flow solutions for the foil geometries prescribed. The primary subroutine here is POTFL; the other subroutines comprising this segment are readily identified on the structure map (Appendix A).

In the calculations performed here the velocity distribution, for a foil, is developed by a superposition of velocity fields. In this regard the velocity contribution due to foil thickness (alone) is added to that due to camber, and this combination is subsequently modified to show the influence of boundary layer (as it develops over the surfaces). In pursuit of this latter effect,the program, controlled by input, has the option of simulating the boundary layer's effects by: (1) modifying the foil's geometry; or, (2) introducing a distribution of source singularities to account for the layer's buildup.

During the first two computational iterations (in this program segment) the velocity distributions due to thickness and camber -- for the basic foil geometry -- are computed. For all subsequent iterates these velocities are

recalculated, accounting for the influence of boundary layer displacement thickness over the basic foil's geometry. Of course, when the viscous boundary layer is neglected the computational procedure is considerably shortened and the need for "iterations" is removed.

Calculations for the velocity fields (due to foil thickness and camber) make use of Oellers' Vortex Distribution Method [5], using the scheme which is outlined in [4]. Incorporated in with these computations is the procedure used (here) to satisfy the Kutta condition for the foils. The procedure used represents a modified Kutta condition wherein the upper and lower surface vortex strengths are matched in magnitude, but assigned opposing signs.

If the viscous boundary layer is simulated by a distribution of source singularities then the subroutine (SOURCE) is called. Otherwise the boundary layer's influence is provided for by modifying the velocity field for foil camber. For those cases where trailing edge thickness is not zero, the velocity field due to thickness is altered through a closure of the geometry one chord length downstream of the true trailing edge.

One difficulty with the present program is that it does not have the ability to handle separated flow (until recently*, this was typical of the various analytical simulations). Another discrepancy, which may be remedied soon, is the manner in which the wake (behind the foil) is modeled; and, the attendant drag increment attributed to such a wake. The present system accounts for the increase in drag solely through an empirical procedure based on tests with truncated airfoils.

Since the velocity field, about the foil, is determined here then the pressure distribution is computed here, also. In addition, should there be any reason to make corrections for compressibility, then this would be the place to do so. (For those readers desiring a concise but illuminating discussion on various aspects of the general theories alluded to, here, reference [6] is recommended.)

*See Reference [15].

3.1.3 The Boundary Layer Computations Section

The boundary layer segment of the HYDRO program is designed to provide needed calculations for the boundary layer's influence. The segment is controlled by the routine BDLYR, with calls being made (primarily) to LAMBL and TURBL. There the laminar and turbulent boundary layer algorithms reside; and there the needed caluclations are made. Since HYDROSAP is designed to analyze a single element foil (only) the confluent boundary layer portions of this segment are not called or exercised.

The subroutine LAMBL is based on the theories of Cohen and Reshotko [7], as modified by Goradia, and work published in Schlichting [8]. In addition to computing the boundary layer thickness, the program determines the (laminar) friction coefficients and establishes laminar separation loci.

The subroutine BLTRAN is called to determine the boundary layer transition points (if the free transition option is prescribed).

The turbulent boundary layer calculations are provided for in the subroutine TURBL. There, the algorithm (used) is based on Truckenbrodt's Integral Method [9], as modified by Goradia. In addition to computing the usual viscous flow parameters, this subroutine also calculates a value for the drag coefficient based on the approximate theory due to Squire and Young [10]. (See the structure map, Appendix A, for details regarding the other subroutines contributing to the boundary layer segment of the program.)

3.1.4 The Hydrodynamic Loading Parameters Section

The last segment of this subprogram is controlled by the subroutine LOADSØ. Here the (usual) force and moment coefficients are computed, using the known pressure and shear force distributions existing on the foil. In this algorithm the incremental coefficients are evaluated for contributions due to C_p and due to C_f ; these are then converted to C_L and C_D values; the moment coefficients at (near) the aerodynamic center (C/4) are

determined; and, the lift-to-drag ratio is established.

With these data in hand the engineer is made aware of the foil's sectional hydrodynamic characteristics -- as these are computed for the deflected shape (geometry) -- and, the last operational step to be performed is the conversion of these loading parameters to pressure loads. The subroutine CPTOP is called for this final conversion operation. After this last task is completed, the loads can be passed to the NONSAP subprogram where the foil's elastic response (deflections) will be ascertained.

3.2 Subroutine Descriptions

In this section of this document a brief word description of all subroutines comprising the HYDRO Subprogram is presented. This information, coupled with the chart shown in Appendix A, will add to the statements above, acting to provide a general understanding of how the subprogram functions.

AIRGM Reads input data for a (multi-component) airfoil, and does the computations needed to describe the geometry of the Panel Model used in the Potential Flow and Boundary Layer Programs.

BDLYR This subprogram serves as a control routine performing the management chores for all Boundary Layer computations.

BLTRAN The Boundary Layer Transition routine; performs those computations needed to determine and describe boundary layer transition phenonema.

CAMBER An algorithm which computes the coordinates for the "equivalent" airfoil; an airfoil modified to account for boundary layer displacement thickness. The new (equivalent) airfoil shape is obtained by adding a camber line (addition) computed by averaging the upper and lower surface displacement thicknesses to the (base) camber line for the basic airfoil geometry.

COMPR This subprogram computes the local pressure coefficient (distribution) using the Karman-Tsien correction (law); also, it established the stagnation point locus (on the airfoil).

CONFBL* A subprogram which provides the computational needs in calculating the confluent boundary layer.

CONF5* Goradia's computational method for a confluent boundary layer, in the "core region".

CONF7* Goradia's computational method for the confluent boundary layer, in the "main region" of the airfoil system (main region 1).

CONF8* Goradia's computational procedure for the confluent boundary layer (in main region 2).

CUBSPL* A computational algorithm used to fit a cubic spline through a curve form, y(x) .

CURV (A Function routine.) Employed to compute surface curvature, at a given airfoil surface location (at a specific Theta locus).

DERV A subroutine which computes derivaties of a tabulated array, Y - F(X) . The method utilized a weighted average of derivatives obained by a quadratic fit to points (J-2, J-1, J), (J-1, J, J+1) and (J, J+1, J+2).

DLIM (A specialize function (routine) called by CONFBL.)

DSTEQ A computational procedure used to "smooth" the DSTAR distribution output from the boundary layer routines.

---

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

PROOT A subprogram which finds the roots of a cubic polynomial. In this routine: A ≡ a coefficient vector, and X ≡ a solution vector, for A(1)+A(2)*X+A(3)*X**2+A(4)*X**3=0; X is complex and X ≡ X(1)+IX(2).

PRTCRD A "print" routine -- "prints" the coordinates of a lofted multi-component airfoil system.

PRTGM A "print" routine -- "prints" the input airfoil geometry, prior to lofting.

READIT A "read" routine -- "reads" the input data for the multi-component, two-dimensional viscous airfoil programs.

SIMSOL A "solution" algorithm -- solves the linear simultaneous set of equations, AX = B, in N-unknowns, and returns the solution in B.

SMOCR A "smoothing" routine -- smooths the input airfoil coordinates by consecutively fitting a least squares polynomial (of degree four) through seven points at a time.

SMOOTH A subprogram designed to smooth an array, Y(X), wherein Y(X) is replaced by a weighted average of Y(X) and the average of two (2) predictions of the Y(X) values obtained from a least squares fit to four (4) values of Y(X) beginning at the j^{th} and $j^{th} - 1$ loci, respectively.

SOURCE A subroutine developed to compute the source singularities (strengths) which will produce the equivalence to a boundary layer displacement thickness.

THKVL An algorithm designed to compute a velocity distribution based on airfoil thickness for a viscous flow airfoil shape oriented at zero degress angle of attack.

GAPA* This routine computes the "gap" distance between forward and after components of a multi-component airfoil system. Gap is defined as the distance from a lower surface trailing edge to the upper surface of a following (after airfoil) element.

GEOM This routine lofts and "panels" each component of a multicomponent airfoil system.

HYDRO The main control (management) routine for the entire computational procedure. This subprogram makes calls to: AIRGM (for input data and geometry calculations pertaining to the aerodynamics model); POTFL (where the potential flow calculations are executed, about the equivalent airfoil shape(s)); BDLYR (where boundary layer properties are established); LOADSØ (where the aerodynamic loads are computed); and to the various graphics routines (where graphics output data are stored, and readied for presentation via a selected mode of presentation).

INPUT** A subprogram which lists input requirements for the multi-component, two-dimensional viscous airfoil program.

INTER An interpolation routine.

KUTTA An algorithm which computes the aerodynamic influence coefficients for a modified Kutta condition. (The condition, as stated, requires that the unit vortex strength(s) vary quadratically over the last four (4) panel (end) points near to the upper and lower surface trailing edge loci; and, that at the trailing edge the upper and lower surface unit vortex strengths be equal in magnitude but opposite in sign.)

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*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

**Not present in the current version of HYDROSAP.

LAMBL The laminar boundary layer algorithm.

LOADSØ This subprogram computes the force and moment coefficients, for the multi-component airfoils, using the known pressure and shear (force) distributions.

OELLER Computes the aerodynamic influence coefficients, for the airfoils' potential flow field, using Oeller's singularity distribution method (see NASA CR-2523 (1975) for a detailed description of the method).

OVRLAP* A computational algorithm which calculates the overlap distance between "forward" and "aft" components of a multi-component airfoil system.

PANEL A subprogram designed to distribute a desired number of (computational) panels over the (profile) surface of an airfoil shape.

POTFL An algorithm for computing the viscous/potential flow about an equivalent multi-component airfoil shape -- one composed of the basic airfoil (geometry) with the boundary layer displacement thickness added.

Note: If IPOT $\equiv$ 0, the viscous boundary layer is simulated as change in geometry; IPOT $\equiv$ 1, the boundary layer effect is simulated by distributed source singularities.

POTVL This subroutine calculates a potential flow velocity distribution, over a multi-component airfoil system, using Oeller's Vortex Distribution Method, but with boundary conditions modified to include a distributed source field.

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

TRANS* A subroutine which is employed to translate and rotate the coordinates of the several airfoil components, of a multi-component system, relative to the basic frame of reference.

TURBL An algorithm developed to compute the turbulent boundary layer properties via the Truckenbrodt Integral Method (as modified by Goradia).

3.3 HYDRO Input

This section gives details on the required input file content to the HYDRO subprogram module. When the HYDROSAP program is operating with SHRTIN = .TRUE., the short form input mode, this file is automatically developed internally. On the other hand, when a specialized user application program is to be employed, the user will necessarily prepare (much of) this file and read it in as program input.

No discussion, or description, of those control cards which are not applicable to the present use of this program (e.g., the confluent boundary layer, and special geometric descriptions) will be given.

HYDRO Input Deck

CARD 1: Title Card FORMAT (9A10)
TITLE - 80 column title.

CARD 2: Foil Component Control Card FORMAT (2F10.0)
NC - Number of foil components (for HYDROSAP this number is unity).

(Continued)

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

NCPC - number of computational points for (each successive) foil component (NCPC $\leq$ NCMAX and $\leq$ 81)

CARD 3: Plot Control Cards FORMAT (4F10.0)

(This card set is machine and hardware dependent -- a description, for plotting, is not given here since the routines currently used are not for export.)

CARD 4: Geometry and Panel Control Cards FORMAT (4F10.0, 4A10)

NPP - Number of pivotal points referenced to (each) foil component ($0 \leq$ NPP $\leq$ NC-1).

SF - Scale factor for (each) foil component (this factor converts component geometry and associated transition points, as well as pivotal point coordinates, to feet).

IOP - Panel distribution option indicator (NCPC-1 panels for each component).

- IOP=0. Panels are distributed so that regions, on the foil surface, with greatest curvature have smaller sized panels.
- IOP=1. Panels are distributed by means of a modified cosine/sinh method.
- IOP=2. Panels are distributed in accordance with (and the same as) the input geometry.

ISMO - Maximum number of coordinate smoothing iterations allowed (for no smoothing set ISMO=0).

CLABEL - 40 column component label.

CARD 5: Pivotal Point Coordinate Description FORMAT (8F10.0)

XP,ZP - Coordinates of a pivotal point, referenced to (each) foil component (card omitted if NPP=0).

CARD 6: Foil Coordinate Count Designation FORMAT (F10.0)

NU - Number of foil upper surface coordinates

CARD 7: Foil Coordinates (upper surface) FORMAT (2F10.0)

XU,ZU - Foil upper surface coordinates in (x,z) pairs -- starting at the leading edge and ending at the trailing edge (input NU cards).

CARD 8: Foil Coordinate Count Designation FORMAT (F10.0)

NL - Number of foil lower surface coordinates.

CARD 9: Foil Coordinates (lower surface) FORMAT (2F10.0)

XL,ZL - Foil lower surface coordinates in (x,z) pairs -- starting at the leading edge and ending at the trailing edge (input NL cards; NOTE THAT NU+NL $\leq$ 200).

Note: CARDS 4 through 9 are input once, per foil, since NC=1 (in the HYDROSAP program).

CARD 10: Foil Component Index Card FORMAT (F10.0)

IM - Index designation for the main (reference) foil component (card omitted when NC=1).

CARD 11: Foil Component Index Card FORMAT (5F10.0)

IC - Index for foil component.

IPP - Index for pivotal point, to be used, in "placing" this component.

ICR - Index for the foil reference component.

IPPR - Index for pivotal point, on the reference component, to be used in "placing" this component.

DELTA - Rotation angle between this component's coordinate frame and the reference component's coordinate frame (in degrees; clockwise rotation is positive).

Note: CARD 11 is repeated NC-1 times (card omitted when NC=1).

CARD 12: Angle of Attack Count Card FORMAT (F10.0)

NA - Number of angles of attack to be input (1 $\leq$ NA $\leq$ 10).

CARD 13: Angles of Attack Described FORMAT (8F10.0)

ALPHA - Angle of attack, in degrees (NA values input).

CARD 14: Mach Number Count FORMAT (F10.0)

NM - Number of freestream mach numbers to be input ($1 \leq NM \leq 10$).

CARD 15: Freestream Mach Numbers Described FORMAT (8F10.0)

FSMACH - Freestream mach number (NM values input).

CARD 16: Added Input Information FORMAT (2F10.0)

CREF - Reference (foil) chord, in feet. (This value is used, internally, to nondimensionalize output quantities.)

RN - Reynold's number, based on reference chord (CREF) and freestream conditions. (TOTAL RN is expressed in MILLIONS.)

CARD 17: Transition Point Description FORMAT (6F10.)

LTRANU - Upper foil surface transition option.
LTRANU=0 implies "free" transition (XTRAN=ZTRAN=0.0).
LTRANU=1 implies "fixed" transition.

XTRANU - Upper surface x-location for a fixed transition.

ZTRANU - Upper surface z-location for a fixed transition.

LTRANL - Lower surface transition option.

XTRANL - Lower surface x-location for a fixed transition.

ZTRANL - Lower surface z-location for a fixed transition.

Note: CARD 17 is repeated NC times (NC=1 in HYDROSAP).

CARD 18: Confluent Boundary Layer Control Card FORMAT (8F10.0)

ICFL - Confluent boundary layer option (NC-1 values input; card omitted if NC=1).

ICFL=0. Do not compute confluent boundary layer for this foil component.

(Continued)

ICFL=1. Compute confluent boundary layer for this foil component.

3.4 HYDRO Output

Output from the HYDRO subprogram, described below, refers to the printed information produced at the GSFC computing center following the successful execution of a typical HYDROSAP run.

The printed output, received from the computing center, consists of all information requested (both as special print output plus the "usual" information provided to the user). These data normally appear as a three tiered compilation consisting of: HYDROSAP input "echo" data; the HYDRO subprogram's output segment; and, the NONSAP output segment. It is the middle segment of the data output which is discussed below.

3.4.1 HYDRO Print-out Information

This output segment begins immediately following the message titled, "END ECHO". This message denotes the terminus for the HYDROSAP input stream, which has been "echoed". Should an echo of the input stream not be requested, then the terminating message would have followed (immediately) the namelist (DRV) echo.

HYDRO output begins with an identification message, followed immediately by a listing of the input foil coordinate data (see section 3.3 for notations and a listing of the input quantities).

The input coordinates are repeated in the same format as the data were entered into the program -- the input calls for these coordinates to be expressed in inches.

Next, a tabulation of the dimensionless, redistributed coordinates -- with arc length (SARC/C) and theta-equivalent point descriptions (THETA) noted in parallel vector arrays. The manner in which this "redistribution"

is made depends on the (user supplied) value given to variable (IOP); see section 3.3 for discussion.

The SARC/C tabulation is included in the output to denote the surface-arc length, to each point station on the foil's surface, measured from the trailing - along the lower surface - and over the upper surface - (back) to the trailing edge. These data (and the theta-distribution table) are of interest to the aero/hydodynamists; they are of small value to the engineer.

Following the table is a section, in the printout, headed "Load Summary Sheet ...". The information listed here (by iteration number) is of more use to the program's monitor than to the engineer seeking information. Nonetheless, for completeness and clarity, some explanatory comments should be made regarding the information contained here.

Recall that for a Viscous/Potential Flow problem the program must operate in an iterative mode, to obtain a solution, in order to account for boundary layer buildup over the foil's surface. (In the event that a "classical" potential flow solution would be called for, there would be no need to "iterate" and a solution would be forthcoming immediately.)

The tabulated data, presented for each iteration, lists the component number (only unity will appear for the HYDROSAP program), followed by the "derived" information. These latter data denote flow-field conditions and the force and moment coefficients which have been determined from the integrated pressure - shear distribution(s). A header line, noting physical conditions for the evaluations precedes the above discussed tabulation. Here a Mach number is displayed since the program requires a small input value, for this parameter, in order to run properly. The Reynold's number show there is a value (calculated) representative of the appropriate conditions for the current problem.

The reader will note that for a (general type) viscous flow solution there will be several iterations required in obtaining a solution; and, that each such iterate will have a tabulation (as described above). Once

an acceptable solution has been achieved, the program does a listing of the "final" values developed within the various program segments.

First, there is a listing headed "Boundary Layer Data" -- this tabulates (by surface coordinates) the layer information. Here a description of the laminar-turbulent regions, over the upper and lower (foil) surfaces is given (by column vectors correspoinding to position). Aside from these loci, the most useful information presented in the tables will be the columns headed "CP" and "CF". These describe the local values for pressure coefficient (CP) and skin function coefficient (CF). The other data listed pertain to a description of the boundary layer solution (DSTARC, THETMC, H and DELTA/C); also listed are local flow conditions (ML), and arc length (S/C) -- as mentioned above.

A notation, following each tabulation, denoting separation, refers to the laminar separation; this and the reattachment message are indicators of other computed flow field conditions which exist because of the boundary layer situation. (The reader is advised (again) that, at present, we are unable to adequately predict "flow separation" from the foil's surface.)

Immediately following the tabulation for boundary layer information is the final load summary table. Here the last predicated values (describing hydrodynamic characteristics, stagnation and transition loci, etc.) for the foil section are listed for the readers' perusal and subsequent use. The last line of the summary makes note of those primary parameters ascertained from the analysis. There the lift coefficient (CL), predicted drag coefficient (CD), the Squire-Young profile drag coefficient (CDSY), moment coefficients (nose and quarter-chord values) and the lift-to-drag ratio (CL/CD) are indicated.

This line summary completes the HYDRO output and signals a termination of the "usual" information displayed from the subprogram.

Following the HYDRO output section is a like listing from the NONSAP subprogram. A discussion of these output data will be found in section 4.

4. DESCRIPTION OF NONSAP - THE NONLINEAR STRUCTURAL ANALYSIS PROGRAM

The finite element program NONSAP (Nonlinear Structural Analysis Program) was originally developed in 1974 [11]. NONSAP may be used to analyze the static or dynamic response of one, two, or three dimensional structures, including the effects of geometric and/or material nonlinearities.

In this section we give a brief overview of NONSAP's capabilities and operation, provide a short description of the various NONSAP subroutines, and describe the NONSAP input format. However, for a more complete and detailed description of the NONSAP theory and operation, the reader is referred to the original program documentation [11,12].

4.1 Program Description

The NONSAP program was developed to solve static or dynamic, linear or nonlinear structural problems. The nonlinearities may be due to material behavior (elastic, hyperelastic, and hypoelastic material models are available) or to the effects of large displacements and large strains. The equations of motion of continuum mechanics governing the behavior of the structure under study are discretized in the space variables through the use of isoparametric finite elements. The equations are discretized in the time variable through either a Wilson-Theta or a Newmark-Beta time integration scheme. The resulting nonlinear equations are solved using an incremental method approach, one which corresponds to a modified Newton iteration scheme.

The structural systems to be analyzed may be modeled using a variety of finite element types; these are:

- one-dimensional truss elements,
- two-dimensional plane stress or plane strain elements,
- two-dimensional axi-symmetric shell elements, and
- three dimensional solid or thick shell elements.

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Since nonlinearities may be due to nonlinear material behavior as well as to large displacements or large strains, there are several material descriptions available in the program. These include:

- an isotropic linear elastic material model,
- an orthotropic linear elastic material model,
- the Mooney-Rivlin model,
- an elastic-plastic material with von Mises or Drucker-Prager yield conditions,
- a variable tangent model, and
- a curve description model.

Currently, the HYDROSAP prgram makes use only of the one-dimensional truss finite element, the two-dimensional plane strain element, and the isotropic linear elastic material model. All nonlinearities are, therefore, geometric. Moreover, HYDROSAP uses NONSAP routines in the nonlinear static solution mode with the "updated Lagrangian" solution procedure. As a consequence, the discussions below will be restricted to those NONSAP procedures and options which are currently employed in HYDROSAP.

4.1.1 Incremental Equilibrium Equations for Structural Systems

Using the well-known and well documented [11,13,14] method of finite elements, the incremental nodal point equilibrium equations for an assemblage of finite elements take the form

$$M\,\ddot{u}(t+\Delta t) + C\,\dot{u}(t+\Delta t) + K(t)\,\Delta u = R(t+\Delta t) - F(t) \tag{1}$$

where

M	= the constant mass matrix,
C	= the constant damping matrix,
$K(t)$	= the tangent stiffness matrix at time t ,
$R(t)$	= the external applied load vector at time t ,
$F(t)$	= the nodal point force vector (of stress-equivalent internal reactions) at time t ,

$u(t)$ = the vector of nodal point displacements, at time t ,

Δu = the vector of nodal point displacement increments from time t to $t+\Delta t$: $u(t+\Delta t) - u(t)$,

t = time, and

Δt = time increment.

Of course, in a static analysis $M=C=0$, while time is regarded only as a loading parameter used for applying the external load in "quasistatic" load increments. Also, in a nonlinear analysis, the solution of (1) yields only approximate solution increments, Δu . In order to improve the solution accuracy and to prevent the buildup of solution instabilities, equilibrium iterations may be used at selected time steps.

In the nonlinear static case an equation system of the form

$$K(t)\ (\Delta u)_{i+1} = R(t+\Delta t) - F_i \quad i=0,1,2,\cdots \tag{2}$$

is solved by iteration. Here $F_0 = F(t)$ and F_i is the vector of stress-equivalent internal reactions corresponding to the displacement vector $u_i(t+\Delta t) = u_{i-1}(t+\Delta t) + (\Delta u)_i$. The solution of (2), by iteration, is clearly a modified Newton method for (1).

4.1.2 NONSAP Solution Process

The complete NONSAP solution process consists of three distinct stages: input, assembly, and step-by-step solution (see Figure 4-1).

Input Stage

In this stage, control and nodal point input are read and/or generated by the program; and equation numbers for the active degrees of freedom at each nodal point are established. In addition, externally applied load vectors are established and then stored on tape. Finally, the element data are ready and/or generated, element connectivity arrays are established, and all element dataare then stored on tape.

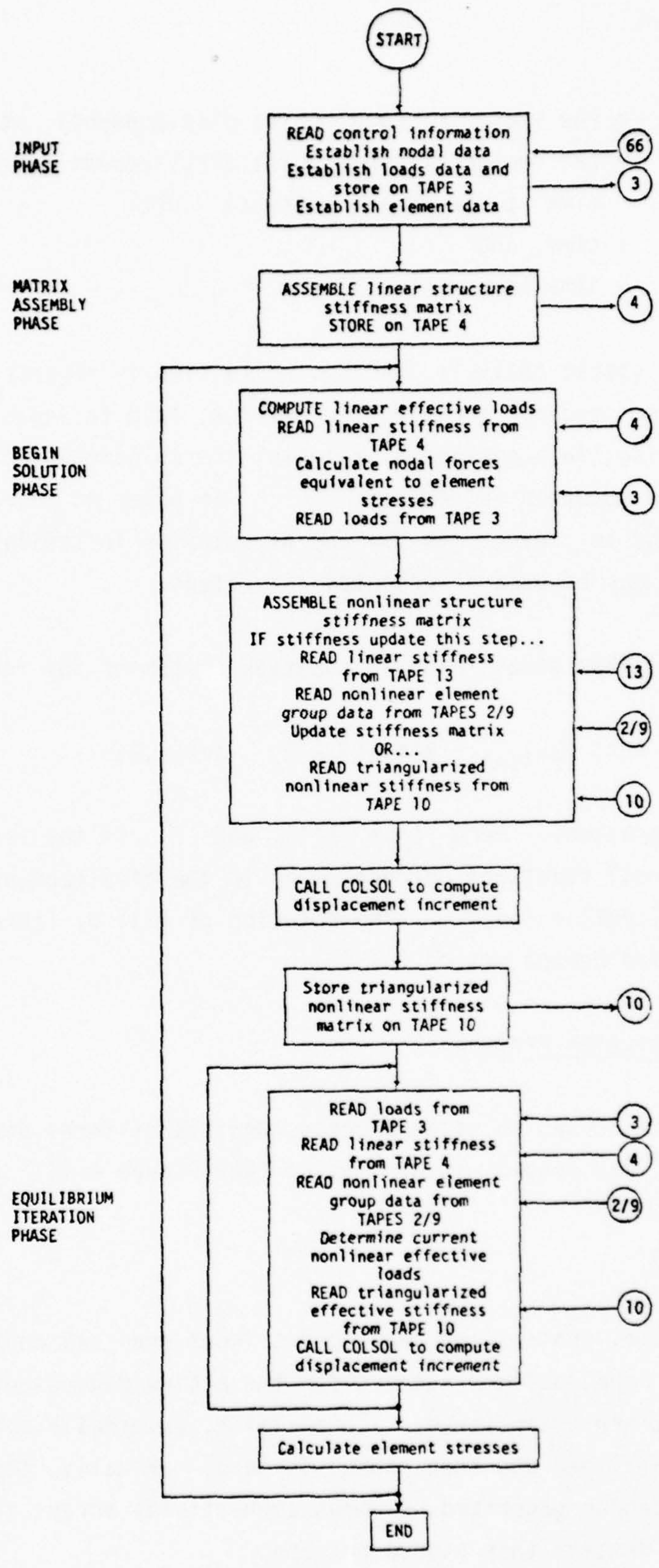

Figure 4-1. NONSAP Flowchart
Program Operation in Nonlinear
Static Solution Mode

Assembly Stage

Here the linear and effective linear structural stiffness matrices are assembled and stored on tape, as are the mass and damping matrices (for a dynamic analysis). Matrices are stored in compacted form as one-dimensional arrays. Only the elements below the "skyline" of a matrix are processed, thereby reducing storage, input/output, and computational costs.

Solution Stage

In a nonlinear static analysis (the solution mode for which NONSAP routines are used by HYDROSAP) damping and mass effects are neglected. Time serves as a loading parameter, only, and the input time step determines the load increment to be applied to the structure during each solution step. The linear stiffness matrix which was previously assembled and stored on tape, is updated at each solution step. This is accommodated by updating the stiffness matrices of the nonlinear elements to form a current tangent stiffness matrix. The load step interval at which this update occurs is one of the NONSAP control inputs.

Moreover, within each load step, solution accuracy may be improved by equilibrium iterations. The interval of load steps at which an equilibrium iteration is to be allowed is also a NONSAP control input.

A solution to the incremental linear equations at each load step is performed by the linear equation solver, COLSOL; a routine which performs Gauss eliminations on the positive definite symmetrical system of equations. This algorithm takes advantage of the banded and sparse structure of the stiffness equations by not processing elements outside a matrix skyline, since they remain zero throughout the computation. The algorithm consists of an LDL^t decomposition of the tangent stiffness matrix into lower triangular, L, and diagonal, D, matrices, followed by a reduction and back substituion of the load vector.

4.1.3 NONSAP Element Library

In this section we will briefly describe only those NONSAP element types which are used by HYDROSAP.

The One-Dimensional Truss Element

A one-dimensional truss element, which may be located in a three-dimensional space, is used in HYDROSAP to model the thin skin which is on the exterior of some cable fairings. This element has two nodes; it is assumed to have a constant cross-sectional area (which corresponds to the skin thickness in the HYDROSAP plane strain analysis) and to undergo small strains and large displacements.

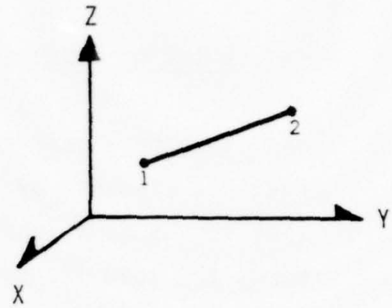

Figure 4-2. A One-Dimensional Truss Element

The Two-Dimensional Plane Stress/Plane Strain Element

An isoparametric plane strain element, having a variable number of nodes, is used to model the interior (cross-section) of the cable fairing. This element may have from three to eight nodes; any of the nodes numbered from five through eight on the sketch may be omitted. A three node element is obtained by setting the coordinates of two nodes, for a four node quadrilateral, equal to each other. In a plane strain analysis the out-of-plane element thickness is assumed to be unity.

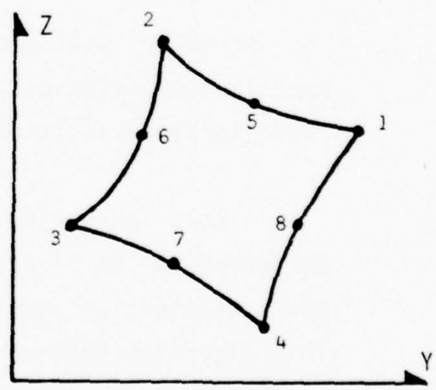

Figure 4-3. A Two-Dimensional Plane Strain Isoparametric Quadrilateral Element

4.2 Subroutine Descriptions

In this section, a brief description of the various NONSAP subroutines is provided. In addition, a structure map of the NONSAP module can be

found in Appendix A.

ADDBAN Assembles upper triangular element stiffness into a compact global stiffness matrix.

ADDCM* Adds nodal masses and dampers to the global mass matrix or to the global effective stiffness matrix.

ADDDI Adds displacement increments to the working displacement array.

ADDMA* Adds element masses to the global lumped mass array.

ADDRES Calculates addresses for diagonal elements in a banded matrix whose column heights are known.

ASSEM Assembles matrices needed in a solution and dumps them to mass storage.

BANDET* Performs triangular factorization and determinant calculations for a banded matrix.

CAUCHY Converts Piola-Kirchoff stresses to Cauchy stresses.

CDMOD* Provides the curve description non-linear material model (for two-dimensional elements).

CMOD3D* Provides the curve description non-linear material model (for three-dimensional elements).

COLHT Computes column heights for a banded sparse matrix.

---

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

COLSOL — The simultaneous linear equation in-core solver routine. It uses compacted storage and a column reduction scheme.

DCRACK* — This routine modifies the stress-strain model to account for material cracking.

DERIQ — A routine which evaluates the strain-displacement matrix for quadrilateral elements with axisymmetric geometry.

DERIQ3 — Evaluates the strain-displacement matrix for the 8 to 21 node curvilinear hexahedron.

DRUCK* — Provides element stresses for the Drucker-Prager non-linear material model.

ELCAL — Makes the calls to appropriate element routines for reading, limited checking, generating, and storing of finite element data.

ELEMNT — Provides for calls to the appropriate one-, two-, or three-dimensional element initialization routines.

ELPAL* — An algorithm to generate the elasto-plastic non-linear material model.

ELT2D3* — The 2-D material model #3: Variable Tangent Moduli Model.

ELT2D4* — The 2-D material model #4 or #5: Curve Description Model.

ELT2D6* — The 2-D material model #6: Von Mises Elastoplastic Model.

ELT2D7* — The 2-D material model #7: Drucker-Prager Elastoplastic Model.

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*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

ELT2D8* The 2-D material Model #8: Incompressible Elastic Model

ELT2D9* A dummy routine for any user-provided non-linear material model.

ELT3D3* The 3-D material model #3: Curve Description Non-linear Model.

$\left.\begin{array}{l}\text{ELT3D4*}\\\text{ELT3D5*}\\\text{ELT3D6*}\\\text{EL2D10*}\\\text{EL2D11*}\\\text{EL2D12*}\end{array}\right\}$ Dummy material models (user-supplied).

EQUIT An iteration scheme used to achieve dynamic equilibrium.

ERROR This routine prints error message if storage requirements exceed program capacity.

FREQS* This routine finds lowest frequencies and mode shapes for the linearized structure.

FUNCT* A subprogram which computes the

- interpolation functions and their derivatives for the curvilinear isoparametric hexahedron (8 to 21 nodes), or the
- Jacobian of element mapping function.

FUNCT2 A routine to compute the

- interpolation functions and their derivatives for the curvilinear isoparametric quadrilateral (4 to 8 nodes), or the
- Jacobian of element mapping function.

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

ICDMOD* An initializing routine for CDMOD.

ICMOD3* An initializing routine for CMOD3D.

IDRUCK* An initializing routine for DRUCK.

IELPAL* An initializing routine for ELPAL.

INITAL Initializes the displacement, velocity, and acceleration arrays.

INITWA* Initializes the working array used with the 2-D non-linear material models.

INPUT A routine which

- reads and prints nodal point data,
- generates missing nodal data, and
- determines equation numbers associated with each node.

INTWA3* Initializes the working array used with the 3-D non-linear material models.

IVTMOD* An initializing routine for VTMOD.

LOADEF An algorithm to calculate effective applied loads (excluding non-linear contributions).

LOADER (A BTS-supplied HYDROSAP routine) converts a pressure distribution to consistent nodal loads and assigns appropriate load-profile multipliers for each direction at every node.

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

LOADS This subroutine

- reads load profiles and interpolates functional values at requested points in time,
- reads nodal load factors, and
- calculates nodal loads for each time step and stores the results on Tape 3.

MATBAR Computes stresses for the 1-D truss elements.

MATRT2 Prints material properties for the 2-D elements.

MATWRT* Prints material properties for the 3-D elements.

MAXAEX* Shifts elements of a working array during the eigenvalue analysis.

MAXMIN An algorithm to calculate principal stresses.

MIDEP* A routine which forms the elasto-plastic material matrix.

MLTPLY* An algorithm to compute A=B*C , where B is a matrix (stored in compacted form) and A and C are vectors.

MOONEY* An algorithm to describe an incompressible nonlinear elastic material (Mooney-Rivlin description in a state of plane stress).

MULT An algorithm to compute A=B*C , where B is a matrix (stored in compacted form) and A and C are vectors.

NDLLDS (A BTS-supplied HYDROSAP routine.) Determines consistent nodal loads from the fairing surface geometry and its pressure distribution.

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*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

NEWDAV This routine calculates the new displacements, velocities, and accelerations at time $t+\Delta t$.

NODMAS* A routine that

- reads concentrated nodal masses and dampers, and
- computes nodal mass and/or damping vectors and stores them on Tape 11.

NONSAP The main program for the NONSAP module, in HYDROSAP. This routine controls NONSAP execution.

NONSPI A subprogram to read NONSAP input files.

OPCOEF This subprogram calculates the coefficients for the time-integration operators used in the Wilson Theta Method or the Newmark Beta Method.

PNORM* An algorithm to compute a matrix pseudo-norm.

POSINV A subprogram used to invert a positive definite matrix.

PRAGER* Forms the elasto-plastic material matrix for the Drucker-Prager material model.

QUADM Calculates the consistent mass matrix for a quadrilateral element.

QUADM3* Calculates the consistent mass matrix for a curvilinear hexahedron.

QUADS Determines the element stiffness matrix for quadrilateral axisymmetric or plane-stress/plane-strain 2-D elements.

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to future users.

QUADS3* Determines the element stiffness matrix for 3-D hexahedral curvilinear elements.

READID Reads the ID array from Tape 8.

RUSS Reads and generates 1-D truss element data; also assembles the 1-D truss elements.

SECANT* This routine computes eigenvalues/eigenvectors for a modal analysis.

STIME An algorithm which computes CPU time (seconds) remaining in a job time estimate.

STRESS Calls subroutine ELEMNT for stress computations.

STSTL Generates the global stress-strain law for isotropic/orthotropic 2-D elements.

STSTN* Generates the stress-strain law and stresses for nonlinear material models.

STST3L* Generates the global stress-strain law for isotropic/orthotropic 3-D elements.

STST3N* Generates stresses for all 3-D models, and the stress-strain law for nonlinear material models.

TDFE This routine controls the generation and assembly of 2-D elements.

THDFE* This routine controls the generation and assembly of 3-D elements.

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*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program amd may be of value to future users.

THREDM* This subroutine

- allocates storage for the 3-D elements, and
- calls THDFE.

TODMFE This routine

- allocates storage for the 2-D elements, and
- calls TDFE.

TTIME An algorithm which computes elapsed CPU time (in seconds) from last call to STIME.

TRUSS This routine

- allocates storage for the 1-D elements, and
- calls RUSS.

VTMOD* The variable tangent moduli material model.

WRITE A subroutine to print displacements, velocities and accelerations.

WRTFRQ A subroutine to print frequencies and mode shapes in an eigen-system analysis.

4.3 NONSAP Input

This section details the contents of the NONSAP input file. With HYDROSAP operating in the SHRTIN = TRUE mode, this file is built automatically. However, for specialized applications the user may wish to construct this file himself. We will omit discussing the NONSAP control

*These subroutines are not required for the single element foils dealt with in the present study; however, they are retained (and discussed) since they constitute a part of the total computational program and may be of value to futureusers.

card groups (such as those governing three-dimensional or dynamic analysis) which are not applicable to a nonlinear, static, plane strain analysis.

A complete discussion of the NONSAP input format is available elsewhere [12].

NONSAP Input Deck

CARD 1:	Heading Card		FORMAT (10A8)
	HED - 80 column title.		
CARDS 2:	Master Control Cards		FORMAT (I5, 6I1, I4, 3I5, 2F10.0, I5)
Card 2.1	NUMP	- Total number of nodal points; = 0, program stops.	
	IDOF(1)	- Master X-translation code = 0, admissible degree of freedom = 1, deleted degree of freedom.	
	IDOF(2)	- Master Y-translation code.	
	IDOF(3)	- Master Z-translation code.	
	IDOF(4)	- Master X-rotation code.	
	IDOF(5)	- Master Y-rotation code.	
	IDOF(6)	- Master Z-rotation code.	
	NEGL	- Number of linear element groups; = 0, all elements are nonlinear.	
	NEGNL	- Number of nonlinear element groups; = 0, all elements are linear.	
	MODEX	- Solution mode; = 0, data check only = 1, execution = 2, restart.	
	NSTE	- Number of solution time steps.	
	DT	- Time step increment.	
	TSTART	- Time at solution start.	
	IPRI	- Output print interval.	

Card 2.2 FORMAT (4I5)

IMASS - Static or dynamic analysis control flag;
= 0, static analysis (use only this value in a full HYDROSAP analysis)
= 1, dynamic analysis with lumped (diagonal) mass matrix
= 2, dynamic analysis with consistent mass matrix.

IDAMP - Damping control flag;
= 0, no damping (use only this value in a full HYDROSAP analysis)
= 1, Rayleigh damping assumed.

IMASSN - Number of concentrated nodal masses.

IDAMPN - Number of concentrated nodal dampers.

Card 2.3 FORMAT (I5)

IEIG - Eigensystem control flag;
= 0, no eigensystem solution
= 1, find lowest frequencies and mode shapes.

Card 2.4 FORMAT (4I5, E10.4)

ISREF - Number of time steps between effective stiffness matrix updates.

NUMREF - Number of allowable stiffnes matrix updates within each time step.

IEQUIT - Number of time steps between equilibrium iterations.

ITEMAX - Maximum number of equilibrium iterations permitted.

RTOL - Relative tolerance used to measure equilibrium convergence.

Card 2.5 FORMAT (I10, 2F10.0)

IOPE - Time integration method;
= 1, Wilson-Theta method
= 2, Newmark-Beta method.

(Continued)

OPVAR(1) - First integration parameter.

OPVAR(2) - Second integration parameter.

Note: This card is read but ignored in a static analysis (IMASS=0).

Card 2.6 FORMAT (4I5)

NPB - Number of blocks for displacement/velocity/acceleration output;
= 0, print all nodal components.

IDC - Displacement print code
= 0, no print
= 1, print.

IVC - Velocity print code.

IAC - Acceleration print code.

Card 2.7 FORMAT (16I5)

IPNODE(1,1)- First node of printout block no. 1.

IPNODE(2,1)- Last node of printout block no. 1.

IPNODE(1,2)- First node of printout block no. 2.

⋮

Note: Leave this card blank if NPB=0.

CARDS 3: Nodal Point Data FORMAT (A1, I4, A1, I4, 5I5, 3F10.0, I5)

CT - Coordinate system for this node;
= (blank), cartesian (X,Y,Z)
= X, X-cylindrical.

N - Node number of this node ($1 \leq N \leq NUMNP$)

PSF	-	Print suppression flag; = (blank), no suppression = A, suppress ordered list of node coordinates = B, suppress list of equation numbers = C, both A and B above.
ID(1,N)	-	X-translation boundary code.
ID(2,N)	-	Y-translation boundary code.
ID(3,N)	-	Z-translation boundary code.
ID(4,N)	-	X-rotation boundary code.
ID(5,N)	-	Y-rotation boundary code.
ID(6,N)	-	Z-rotation boundary code.
X(N)	-	X (or Z) coordinate (inches).
Y(N)	-	Y (or R) coordinate (inches)
Z(N)	-	Z (or θ) coordinate (inches or radians)
KN	-	Node number increment for automatic nodal data generation

Note: Input one card per node being defined.

CARDS 4: Applied Loads Data FORMAT (3I5)

Card 4.1

NLOAD	-	Number of nodal load cards.
NLCUR	-	Number of load profile time functions.
NPTM	-	Maximum number of points used to describe any one load curve

Cards 4.2 Load Curve Data

Card 4.2.1 Control Data FORMAT (2I5)

NTF	-	Time function number ($1 \leq NTF \leq NLCUR$)
NPTS	-	Number of ordered pairs defining the time function ($2 \leq NPTS \leq NPTM$).

Card 4.2.2 (T,F(T)) Pairs FORMAT (8F10.0)

TIMV(1)	-	Time, T , at point 1.
RV(1)	-	Function value, F(T) , at point 1.
TIMV(2)		

(Continued)

RV(2)

⋮

TIMV(NPTS)

RV(NPTS)

Card 4.2.3 Nodal Loads Data FORMAT (3I5, F10.0)

Note: Skip this card if NLOAD=0 , otherwise input NLOAD cards.

NOD - Node number to which this load is applied.

IDIRN - Degree of freedom (direction) in which this load is applied;
= 0, solution terminated
= 1, X-translation
= 2, Y-translation
= 3, Z-translation.

FAC - Function multiplicative factor used to scale F(T) for this load.

CARD 5: Rayleigh Damping Specification FORMAT (2F10.0)

(Omit this card if IDAMP = 0.)

ADAMP - Rayleigh damping coefficient α .

BDAMP - Rayleigh damping coefficient β .

CARDS 6: Concentrated Nodal Masses FORMAT (I10, 6F10.0)

(Omit these cards if IMASSN = 0 , otherwise input IMASSN cards.)

N - Node number.

XMASS(1) - X-direction mass.

XMASS(2) - Y-direction mass.

XMASS(3) - Z-direction mass.

XMASS(4) - X-rotational mass.

XMASS(5) - Y-rotational mass.

XMASS(6) - Z-rotational mass.

CARDS 7: Concentrated Nodal Dampers FORMAT (I10, 6F10.0)

(Omit these cards if IDAMPN = 0 , otherwise input IDAMPN cards.)

N - Node number.

XDAMP(1) - X-direction damper.

XDAMP(2) - Y-direction damper.

XDAMP(3) - Z-direction damper.

XDAMP(4) - X-rotation damper.

XDAMP(5) - Y-rotation damper.

XDAMP(6) - Z-rotation damper.

CARDS 8: *Initial Conditions*

Card 8.1 FORMAT (I5)

ICON - Initial condition flag

= 0, zero initial conditions generated automatically

= 1, non-zero initial conditions read from input.

Cards 8.2 FORMAT (6E12.)

DISP(1) ⋮ DISP(NEQ) } Initial displacement vector, NEQ = number of equations.

VEL(1) ⋮ VEL(NEQ) } Initial velocity vector (omit if IMASS = 0).

ACC(1) ⋮ ACC(NEQ) } Initial acceleration vector (omit if IMASS = 0).

CARDS 9: Truss Elements

(omit group if no truss elements present.)

(Continued)

Cards 9.1 Element Control Card FORMAT (20I4)

NPAR(1) - = 1

NPAR(2) - Number of truss elements in this group (≥ 1)

NPAR(3) - Type of analysis:

= 1, material nonlinearity only

= 2, updated Lagrangian

NPAR(4) ⋮ NPAR(14) - not used

NPAR(15) - Material model number;

= 1, linear elastic

= 2, nonlinear elastic

NPAR(16) - Number of different sets of material section properties (≥ 1)

NPAR(17) - Number of material model constants per set;

= 0, if NPAR(15) = 1

≥ 4, if NPAR(15) = 2

Cards 9.2 Linear Elastic Material/Section Property Cards

(Omit this group is NPAR(15) ≠ 1, otherwise read NPAR(16) sets of cards.)

Card 9.2.1 Material Number FORMAT (I5)

N - Material/Section number (1≤N≤NPAR(16))

Card 9.2.2 Properties FORMAT (4F10.0)

E(N) - Young's modulus (psi)

AREA(N) - Cross-section area (in^2)

DEN(N) - Mass density (slugs)

STRAI(N) - Initial axial strain (in/in).

Card 9.3 Nonlinear Elastic Material/Section Property Cards

(Omitted...not applicable for the linear material models assumed in HYDROSAP.)

CARDS 10: 2/D Continuum Elements

Card 10.1 Element Group Control Card FORMAT (20I4)

NPAR(1) - = 2

NPAR(2) - Number of elements in this group ($\geq$ 1)

NPAR(3) - Type of analysis;

= 1, material nonlinearity only

= 2, total Lagrangian

= 3, updated Lagrangian

NPAR(4) - Not used

NPAR(5) - Element type

= 0, axisymmetric

= 1, plane strain

= 2, plane stress

NPAR(6) - Not used

NPAR(7) - Maximum number of nodes in any element ($4 \leq NPAR(7) \leq 8$)

NPAR(8), NPAR(9) - Not used

NPAR(10) - Numerical integration order to be used in Gauss quadrature ($2 \leq NPAR(10) \leq 4$)

NPAR(11), NPAR(12) - Not used

NPAR(13) - Number of stress output location tables;

= 0, print stresses at integration points

NPAR(14) - Not used

NPAR(15) - Material model number ($1 \leq NPAR(15) \leq 12$)

= 1, linear isotropic

= 2, linear orthotropic

= 3, variable tangent moduli

= 4, curve description model

= 5, curve description with tension cutoff

= 6, elastic-plastic (von Mises)

= 7, elastic-plastic (Drucker-Prager)

(Continued)

= 8, incompressible nonlinear elastic (Mooney-Rivlin)

= 9, user-supplied material model

NPAR(16) - Number of sets of material properties

NPAR(17) - Number of material constants per property set:

= 0, if NPAR(15)<9

= 1, if NPAR(15)≥9

NPAR(18) - Dimension of storage array required for element history;

= 0, if NPAR(15)<9.

Cards 10.2 Material Property Data

Input NPAR(16) sets of cards

Card 10.2.1 Material Number FORMAT (I5, F10.0)

N - Material number

DEN(N) - Mass density of material (slugs)

⋮

Card 10.2.2 Material Property Cards FORMAT (2F10.0)

(The format is given for NPAR(15)=1 only. Other material models are not used in HYDROSAP.)

PROP(1,N) - Young's modulus (psi)

PROP(2,N) - Poisson's ratio

Card 10.3 Stress Output Tables

(Not applicable...omit.)

Card 10.4 Element Data Cards FORMAT (I5, I3, I2, 2F10.0, 10I5)

M - Element number (within this group)

IEL - Number of nodes used to describe this element

IPS - Number of the stress table to be used for this element;

= 0, no stress output for this element

BET - Material angle, β , used with the linear orthotropic material model

(Continued)

	THIC	- Element thickness (applies to plane stress only) (inches).
	MTYP	- Material property set number assigned to this element
	KG	- Node generation parameter for missing elements
	NOD(1)	- Global node number of element nodal point 1
	⋮	
	NOD(8)	- Global node number of element nodal point 8.
CARDS 11:	3/D Continuum Elements (Not used in HYDROSAP...omitted.)	
CARDS 12:	Eigensystem Solution (Not used in HYDROSAP...omitted.)	

4.4 NONSAP Output

In this section we discuss the output format of the structural analysis module. The output for a sample analysis is discussed in detail in section 5. The NONSAP output (written to an output unit defined by HYDROSAP variable IWRTØ) may be divided into two broad classes: problem definition output and displacement output.

4.4.1 Problem Definition Output

Problem definition output follows the problem title and consists of a summary of user-supplied -- as well as program-generated -- control information for the run; nodal point data; equation number assignments; nodal loads data; and element definition data. The list of control information for the run is for the most part self-explanatory. The nodal point data gives the boundary condition codes (1=constrained, 0=free) for each nodal degree of freedom and the cartesian coordinates for each node. The equation number data identifies the equation associated with each active degree of freedom in the structure.

The nodal loads are defined by a combination of (non-dimensional) load profile time function(s) and specific load curve multipliers which correspond to each structural degree of freedom (node and direction). When NONSAP is being used as part of HYDROSAP, in the "full" iteration mode, the load curve multipliers are determined automatically from the fairing's (deformed) geometry and current surface pressure distribution. The load curve multipliers represent consistent finite element concentrated loads which are work-equivalent to the fairing's surface pressure distribution. The load profile time function defined by the HYDROSAP short form input pre-processor is shown in Figure 4-4. Note that the convention used in HYDROSAP is to relate the value of the NONSAP variable TIME to the HYDROSAP "outer" iteration number: at the start of a NONSAP computation, in an outer iteration ITER,

$$TIME = FLOAT(ITER-1) \quad .$$

Thus, for example, during HYDROSAP outer iteration number five, TIME increases from TIME=4.0 to TIME=5.0 . In the current HYDROSAP version the time is incremented to steps of size DT=1.0 , except during outer iteration ITER=1 . During this first outer iteration TIME is incremented in NSTE (≡HYDROSAP control variable NSTEPS) steps of size DT=1/NSTE . Due to the shape of the load curve profile (Figure 4-4), this procedure has the effect of loading the original fairing with the first HYDRO pressure distribution in "NSTE" quasistatic load steps.

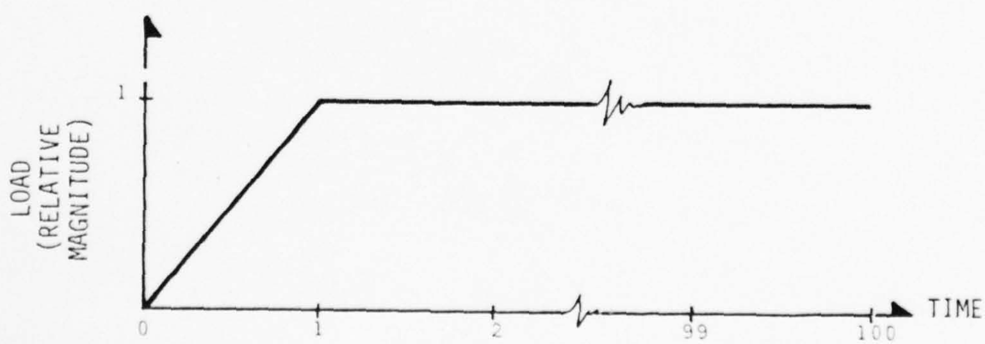

Figure 4-4. HYDROSAP Non-Dimensional Load Profile

The element definition data is reported in element groups. Elements within a group are of the same type (1-D Truss, 2-D quadrilateral, 3-D Hexahedral), the same degree of nonlinearity, the same sub-type (axisymmetric, plane strain, plane stress); and, have the same type of material model. There may be several material property sets for each group, however. For example, fairing CORE and TAIL elements are 2-D quadrilateral, plane strain, updated Lagrangian, isotropic elements which have differing elastic properties. Elements are numbered within each group, and a "connectivity" table is printed which identifies the global nodes defining each element.

4.4.2 Displacement Output

Following the problem definition data, the program prints the initial displacements for each node, and then the computed nodal displacements after every IPRI (≡ HYDROSAP control variable IPRINT) steps during the solution process. Note that for HYDROSAP calculations all displacements are zero except those in the Y-Z plane. This is the reference plane for a NONSAP plane strain analysis. The Y-direction is defined by the undeformed fairing chord, and the Z-direction is transverse to the chord. (Note that the corresponding HYDRO coordinate system is described in the X-Z plane.)

5. SAMPLE ANALYSIS

To illustrate the capabilities of the HYDROSAP software system, the results of a sample analysis are discussed in this section. A hypothetical 3 inch chord faired cable of NACA 0020 section was "towed" through the water at 44 fps (34.5 knots) with an angle of attack of 8°.

Structurally, the towline section was modelled as having a rigid (ECORE = 1×10^6 psi) CORE extending aft from the leading edge for 3/4" (Y1CORE = 0.0, Y2CORE = 0.75). The afterbody, or TAIL, was defined to be a relatively flexible rubber-like material (ETAIL = 1×10^4 psi). The entire fairing section was enclosed by a very flexible SKIN (ESKIN = 2×10^3 psi), 0.05 inches thick (TSKIN = 0.05). The finite element mesh used to analyze the structural response was generated automatically by the software (MESHC = 11, MESHT = 3). The mesh consisted of 48 2-D elements having 57 nodes; the outer SKIN connecting the surface nodes was modelled by 24 1-D elements.

For the purposes of the hydrodynamic computations, the fairing's NACA 0020 surface profile was modelled by 35 surface points distributed automatically (HYDROSAP controls IPANEL = 2, and N = - 3 ... for FOILØ3) on the upper and lower fairing surfaces by the software. Viscous effects were included in the computations in each of the HYDROSAP "outer iterations" (ITRSWT = 1).

The effect of the hydrodynamic loading on the flexible symmetric fairing was to induce negative camber. Figure 5-1 summarizes the types of deformations suffered by the fairing cross-section. Evidently, the material above the fairing chord was compressed, while that below was in tension. The equilibrium trailing edge transverse deflection was approximately 2.3% of the chord.

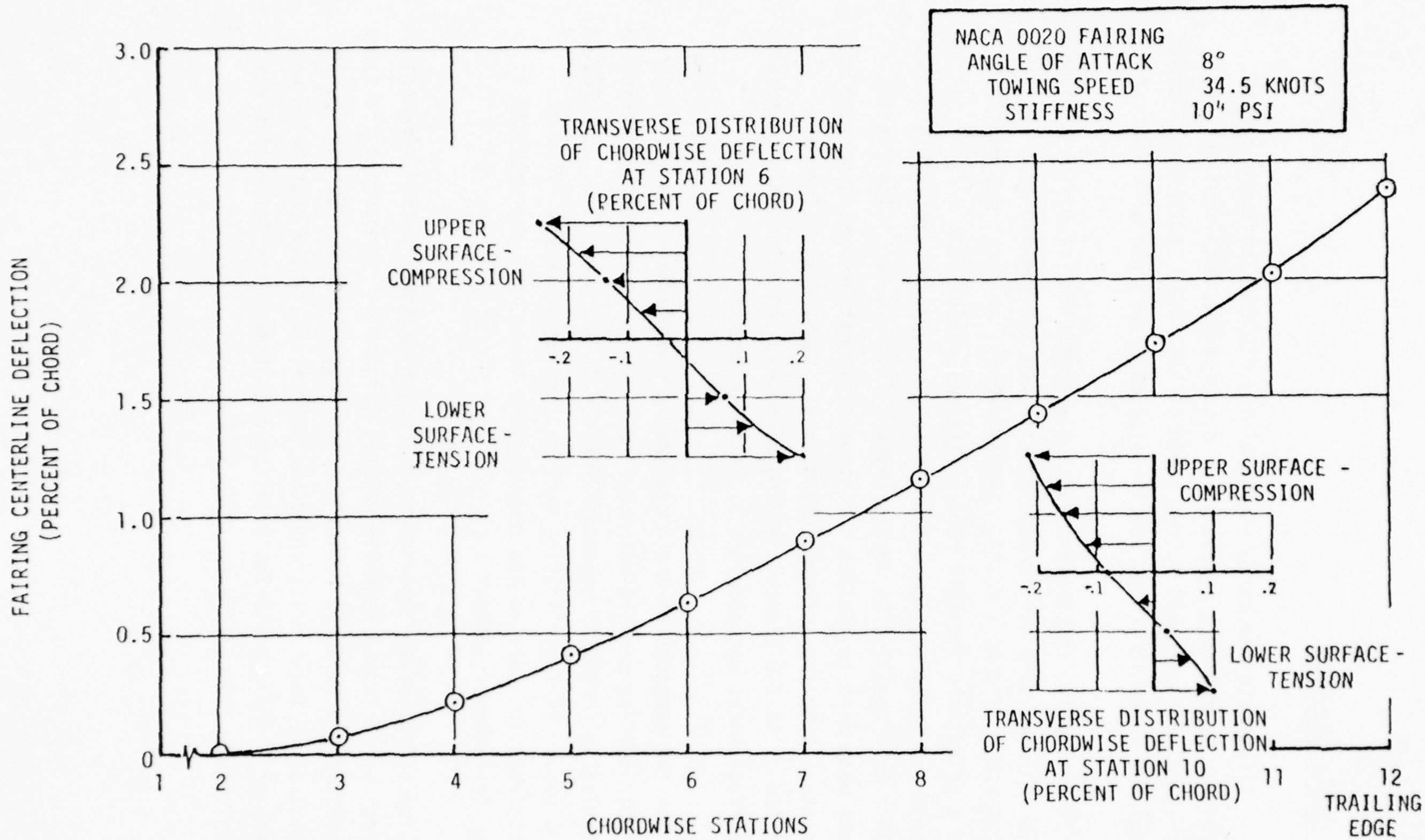

Figure 5-1. TRANSVERSE DEFLECTION OF CENTERLINE FOR A FLEXIBLE CABLE FAIRING

The negative camber acted to reduce the magnitude of the lift and (nose) moment coefficients significantly. In Figure 5-2, the hydrodynamic coefficients are plotted for each successive pass through the HYDROSAP system. It is evident from the graph that after 10 iterations the hydrodynamic loading and structural response are in equilibrium. The fairing's deformation has reduced the lift coefficient by 24%, from $C_L = .8996$ for the undeformed fairing, to $C_L = .6794$ for the deformed fairing. The nose-down moment coefficient, taken about the leading edge, has been reduced by 29%. Figure 5-3 shows the effect that the modest chordwise deflection of the fairing has on the pressure distribution. The pressure coefficients are reduced in magnitude by about 10% to 20% even in the rigid leading edge region. The trailing edge deflection evidently makes its presence felt globally over the fairing surface.

It is clear that the chordwise flexibility of a towline fairing can have significant effect upon the fairing's hydrodynamic properties.

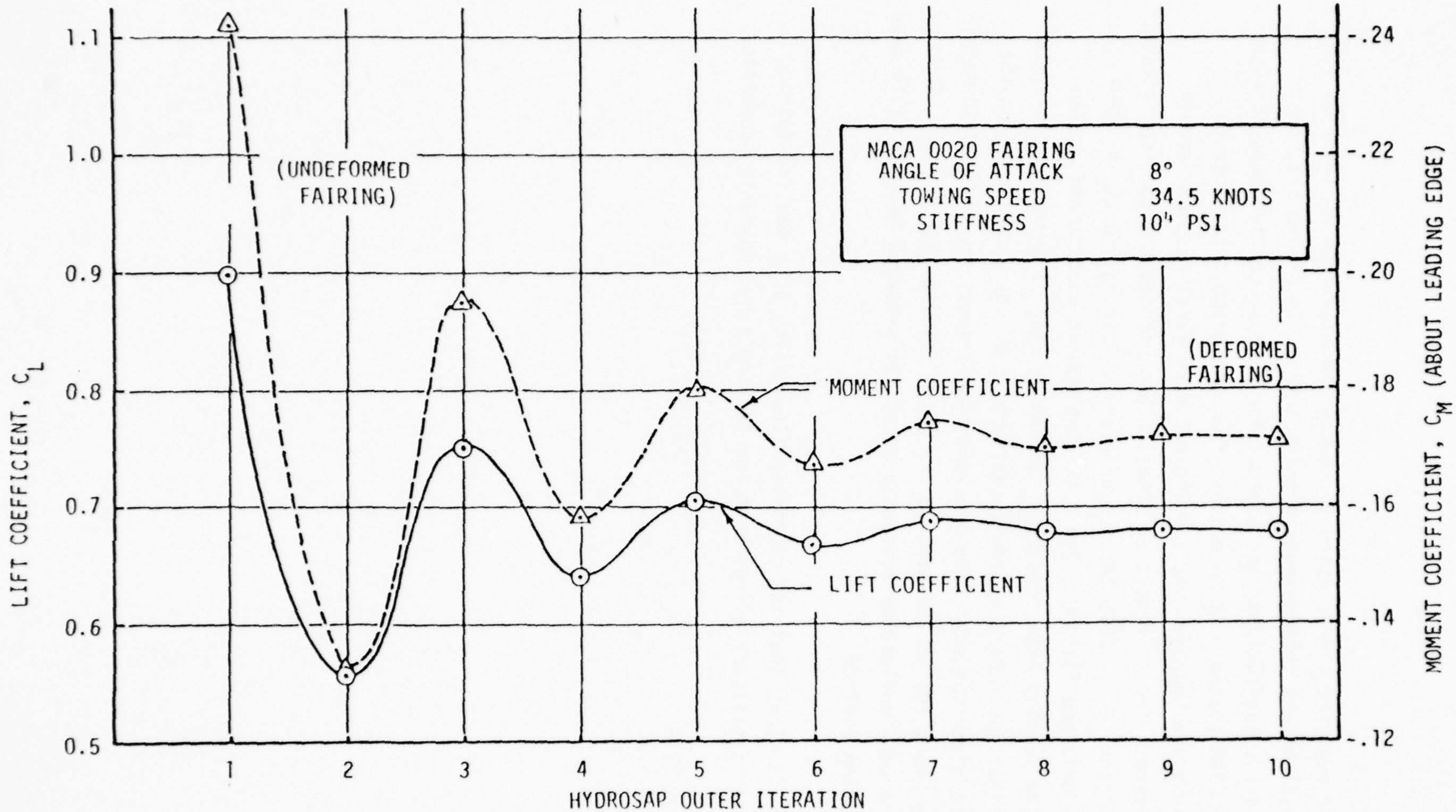

FIGURE 5-2. HYDRODYNAMIC COEFFICIENTS FOR A FLEXIBLE CABLE FAIRING

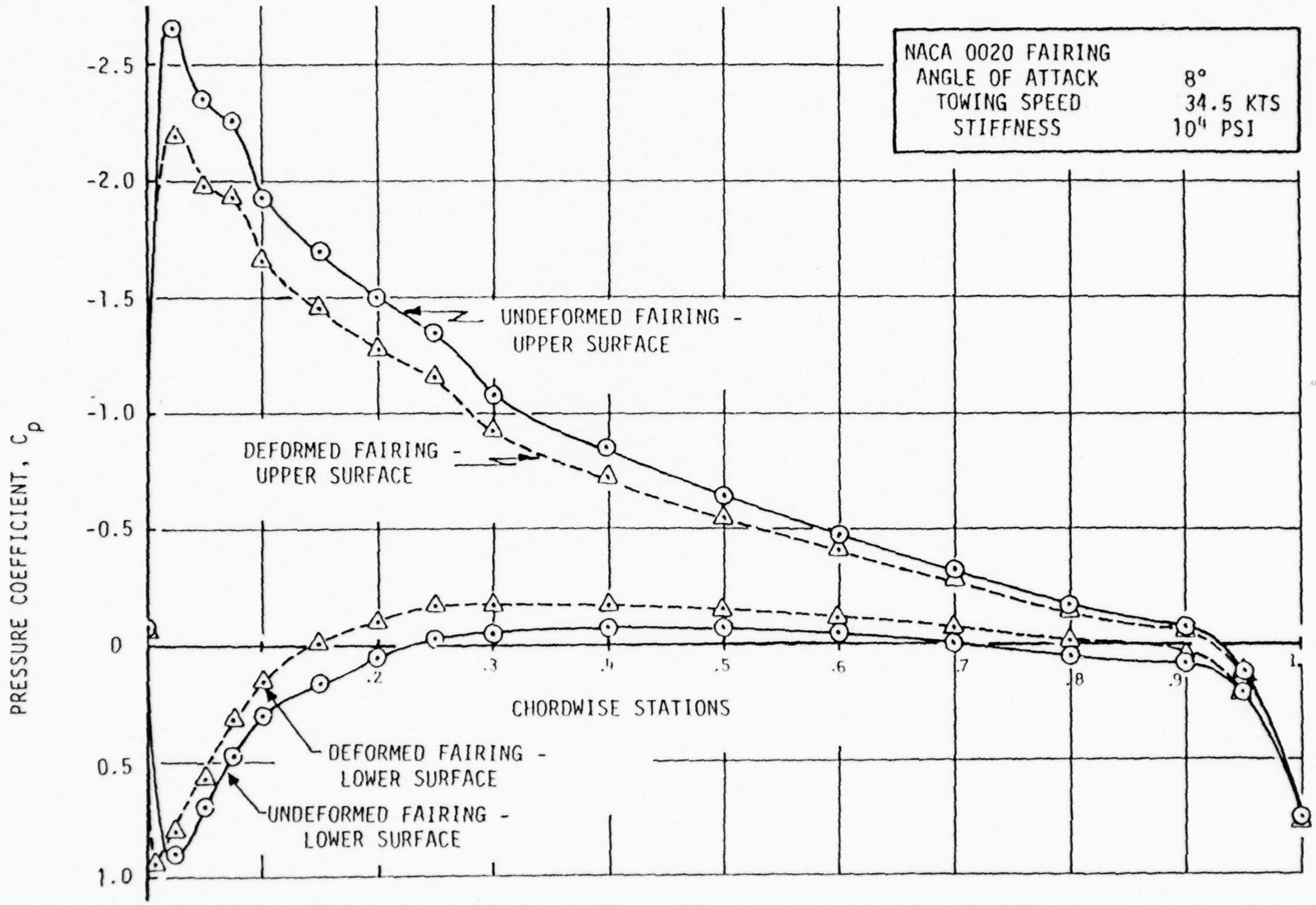

FIGURE 5-3. PRESSURE DISTRIBUTIONS OVER UNDEFORMED AND DEFORMED FAIRINGS

6. References

(1) Stevens, W. A., S. H. Goradia, and J. A. Braden; "Mathematical Model for Two-Dimensional Multi-Component Airfoils in Viscous Flow". NASA CR-1843, July 1971.

(2) Brune, G. W. and J. W. Manke: "An Improved Version of the NASA/Lockheed Multi-Element Airfoil Analysis Computer Program". NASA CR-145323, March 1978.

(3) Morgan, H. L., Jr.: "A Computer Program for the Analysis of Multi-Element Airfoils in Two-Dimensional Subsonic, Viscous Flow". Aerodynamic Analyses Requiring Advanced Computers Conference. NASA/Langley Research Center, Hampton, Virginia, March 1975.

(4) Smetana, F. O., D. C. Summey, N. S. Smith and R. K. Carden: "Light Aircraft Lift, and Drag, and Moment Prediction - A Review and Analysis". NASA CR-2523, May 1975.

(5) Oeller, H. J.: "Die inkompressible Potentialströmung in der ebenen Gitterstufe (Incompressible Potential Flow in Two-Dimensional Cascades)". Wissenschaftliche Gessellschaft für Luft-und Raumfahrt E. V., pp. 349-353, Jahrbuch 1962 (In German, not translated).

(6) Karamcheti, K.: Principles of Ideal-Fluid Aerodynamics, John Wiley & Sons, Inc., New York/London/Sidney, 1966.

(7) Cohen, C. B. and E. Reshotko: "The Compressible Laminar Boundary Layer with Heat Transfer and Arbitrary Pressure Gradient" NASA TND-1294, 1956.

(8) Schlichting, H.: Boundary Layer Theory. Sixth Ed., McGraw-Hill, New York, 1968.

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(9) Truckenbrodt, E.: "Ein Quadraturuerfahren zur Berchnung der laminaren und turbulenten Reibungsschift bei ebener und rotationssymmetrischer Strömung". Ing. Arch., vol. 20, pp 221-228, 1952 (NASA TM-1379, 1955).

(10) Squire, H. B. and B. A. Young: "The Calculation of the Profile Drag of Airfoils", RAE Report R&M No. 1838, November 1937.

(11) K. J. Bathe, H. Ozdemir, and E. L. Wilson, "Static and Dynamic Geometric and Material Nonlinear Analysis", Report No. UC SESM 74-4, Structural Engineering Laboratory, Department of Civil Engineering, University of California, Berkeley, California, 1974.

(12) K. J. Bathe, E. L. Wilson, R. H. Iding, "NONSAP: A Structural Analysis Program for Static and Dynamic Response of Nonlinear Systems", Report No. UC SESM 74-3, Structural Engineering Laboratory, Department of Civil Engineering, University of California, Berkeley, California, 1974.

(13) J. T. Oden, Finite Elements of Nonlinear Continuua. McGraw-Hill, 1972.

(14) O. C. Zienkiewicz, The Finite Element Method in Engineering Science, McGraw-Hill, London, 1971.

(15) Dvorak, F. and B. Maskew: "The Prediction of $C_{\ell max}$ using a Separated Flow Model". Proceedings of the 33rd AHS Meeting, 1977 (Paper No. 77.33.01.) Also, Journal American Helicopter Society, April 1978.

APPENDIX A

HYDROSAP Overlay Structure

HYDROSAP Overlay Structure

In order to retain the full capabilities of the HYDRO and NONSAP modules, which comprise HYDROSAP, and yet keep the entire HYDROSAP system's core requirements to a minimum, an extensive overlay structure has been prepared. Currently the system requires approximately 390 k bytes of core. A version without overlay would require over 600 k. Maps of the overlay structure are given in Figures A-1, A-2, and A-3.

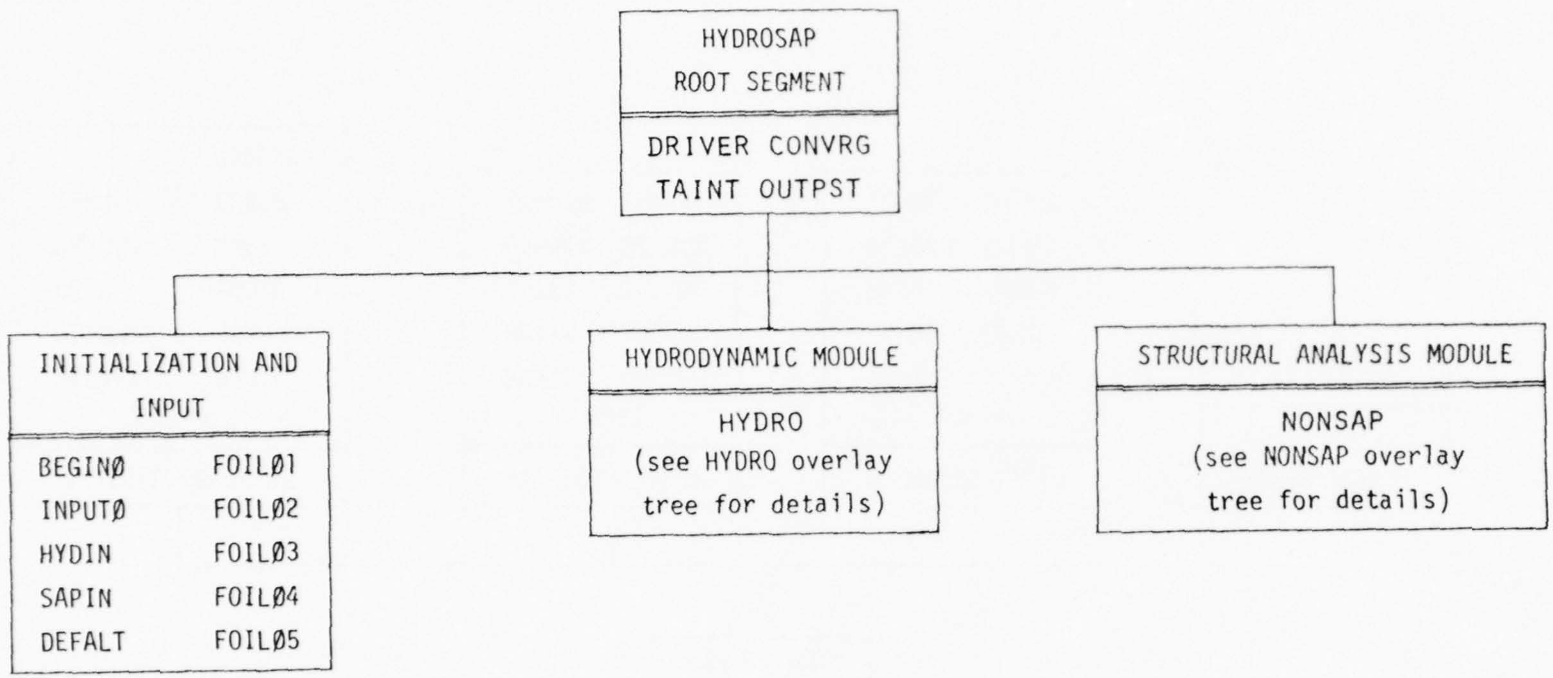

Figure A-1. HYDROSAP Overlay Tree

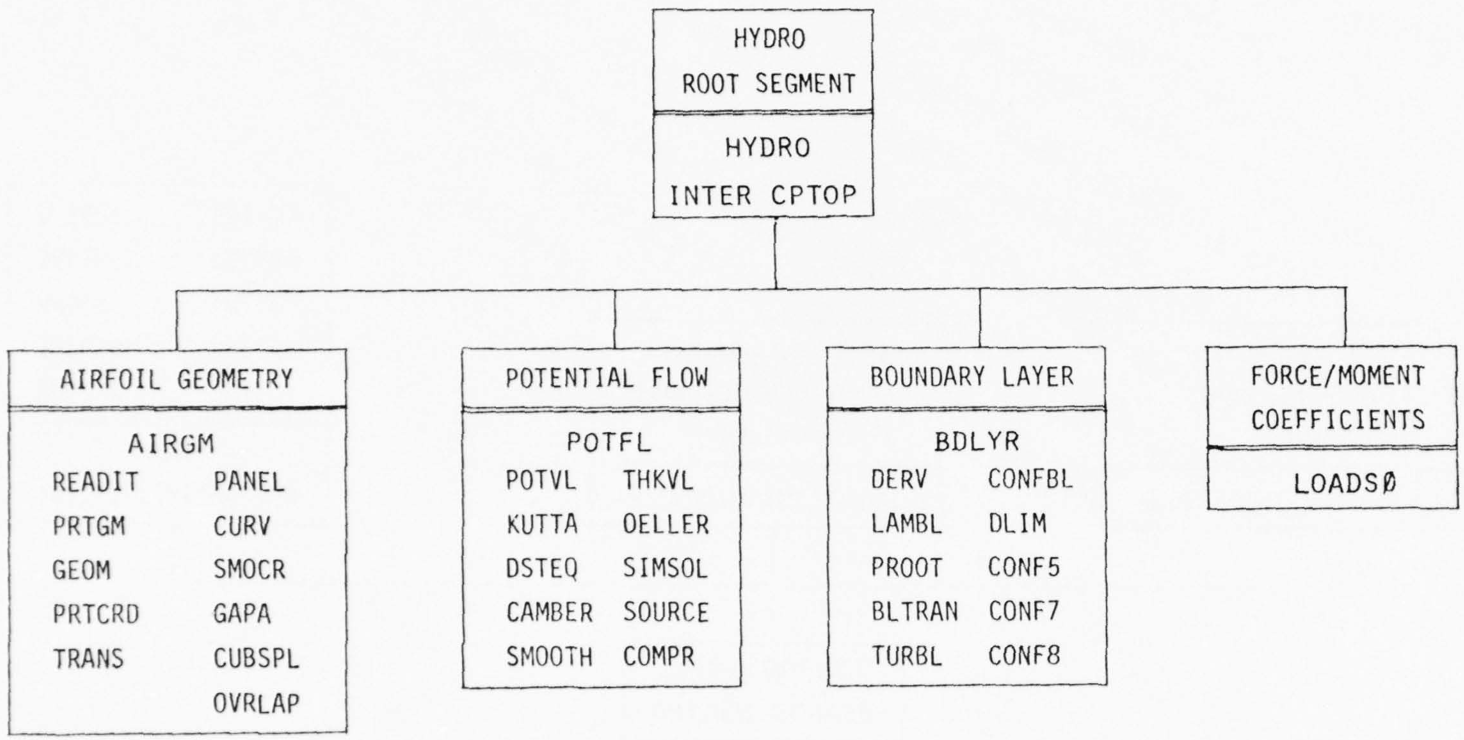

Figure A-2. HYDRO Overlay Tree

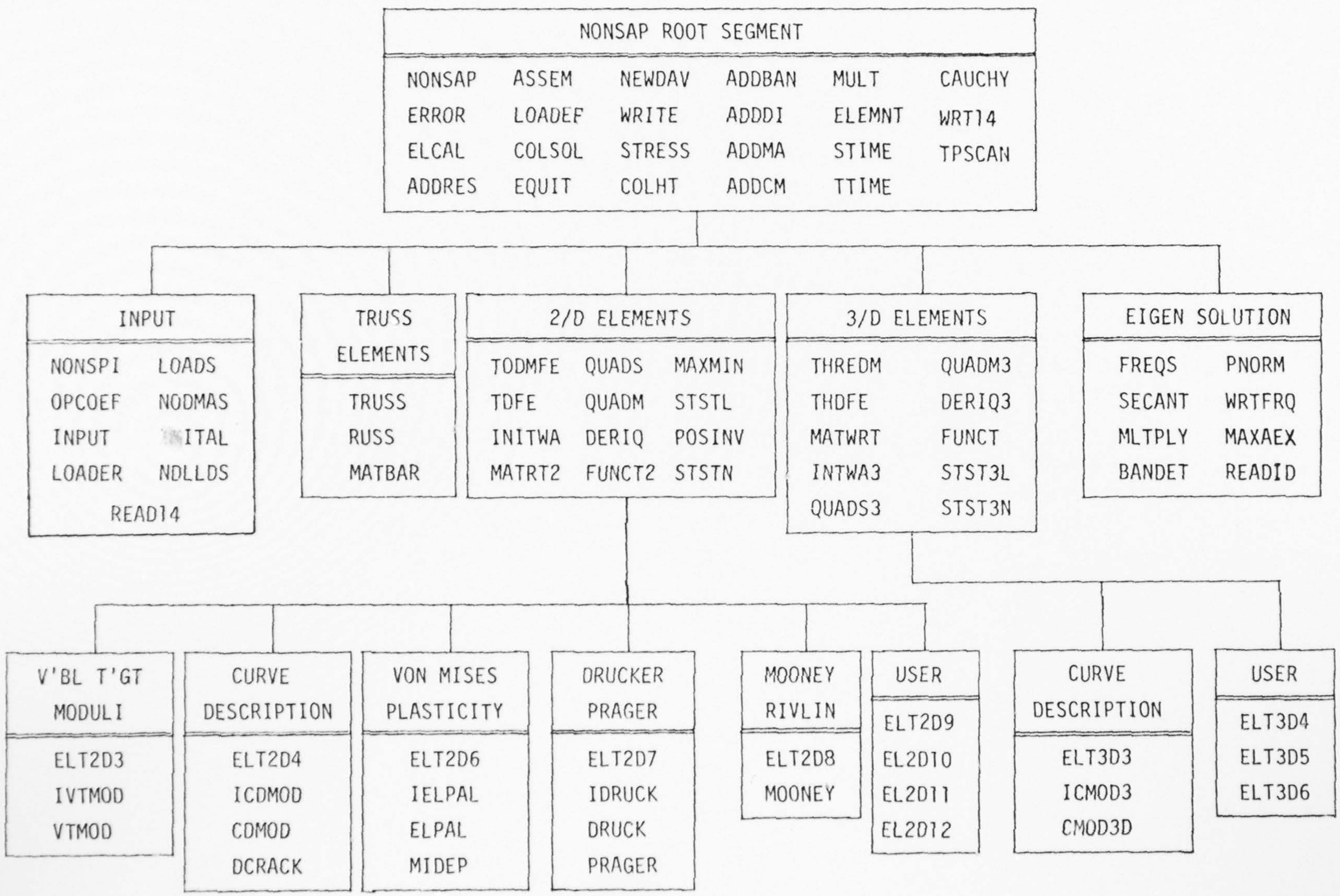

Figure A-3. NONSAP Overlay Tree

APPENDIX B

HYDROSAP Auxiliary Subroutine Descriptions

Subroutine: BEGINØ

FUNCTION:

BEGINØ initializes HYDROSAP variables and sets default values for the control variables brought in via NAMELIST /DRV/ (see subroutine INPUTØ).

CALLING SEQUENCE:

Call BEGINØ

COMMON BLOCKS:

/INTGRØ/	/LOGICØ/
/INTGR1/	/REALØ/
/INTGR2/	/ARRAYØ/
/SURFCE/	

I/O UNITS:

None.

PRINCIPAL VARIABLES:

See subroutine INPUTØ.

EXTERNAL REFERENCES:

None.

CALLED BY:

DRIVER

Subroutine CONVRG

FUNCTION:

CONVRG tests the size of the current displacement increment, relative to the total displacement, against a user-assigned tolerance value. CONVRG is called after each of the NONSAP displacement computations, in each HYDROSAP outer iteration.

CALLING SEQUENCE:

Call CONVRG (DISP, DISPI, NEQ, TOL, ISTOP).

COMMON BLOCKS:

/INTGRØ/
/LOGICØ/

I/O UNITS:

Unit IPAPER	= 6 for printer output
	= 22 for dummy
Unit 12	Terminal summary output.

PRINCIPAL VARIABLES:

DISP	array of displacements at each of the NONSAP nodes (input)
DISPI	array of displacement increments at each of the NONSAP nodes (input)
NEQ	number of equations (active degrees of freedom) in NONSAP (input)
TOL	tolerance level assigned for the convergence test (input)

ISTOP convergence status (output)

= 0 not converged; proceed with next HYDROSAP outer iteration

= 1 convergence achieved; normal termination

= 2 displacement increments all zero; error termination.

EXTERNAL REFERENCES:

*DSQRT FORTRAN Double-precision square root function.

CALLED BY:

DRIVER

---

*A standard (machine) routine.

Subroutine DEFALT

FUNCTION:

DEFALT calls the appropriate fairing profile library routine for short form input (SHRTIN=.TRUE.), based upon user control input (variable N).

CALLING SEQUENCE:

Call DEFALT (X,Z,N).

COMMON BLOCKS:

None.

I/O UNITS:

None.

PRINCIPAL VARIABLES:

X,Z	an array of fairing upper surface coordinates expressed in inches (output). X(I) = chordwise location, for the I^{th} station Z(I) = fairing local semi-thickness, at the I^{th} station (X(1), Z(1)) = leading edge (X(N), Z(N)) = trailing edge
N	= fairing library shape routine (input) = number of profile points (output).

EXTERNAL REFERENCES:

FOILØ1 FOILØ2 ⋮	Library of fairing cross-section (upper profile) arrays. [Only FOILØ1 through FOILØ5 are currently implemented.]

FOILØ5

⋮

FOIL99

CALLED BY:

HYDIN

Program DRIVER
(alias HYDROSAP)

FUNCTION:

DRIVER is the main HYDROSAP executive routine. It controls the HYDRO and NONSAP program modules, as well as the program initialization input file preparation, convergence testing, and the graphics post-processor output.

COMMON BLOCKS:

/INTGRØ/	/LOGICA/
/INTGR1/	/SURFCE/
/INTGR2/	/ARRAYØ/
/REALØ/	/ARRAY1/
/LOGICØ/	

I/O UNITS:

Unit 5	System input stream (SYSIN)
Unit 12	Terminal summary output (SYSOUT=X)
Unit IPAPER = 6	printer output (SYSOUT=A)
= 22	dummy output
Unit IREADØ	NONSAP Input File (=55)
Unit IREAD1	HYDRO Input File (=66)

PRINCIPAL VARIABLES:

SAPSIM	= .TRUE., NONSAP simulation mode only
HYDSIM	=.TRUE., HYDRO simulation mode only
SHRTIN	=.TRUE., short form input; results in an automatic construction of the HYDRO and NONSAP input files
TPRINT	=.TRUE., terminal print summary requested (SYSOUT=X)
ECHO	=.TRUE., "echo" of HYDRO and NONSAP input files is produced
POST	=.TRUE., graphics post-processor output is produced

ITER	HYDROSAP outer iteration counter (value written).
LOOPMX	maximum allowable value for ITER
ITRSWT	if ITER.GE.ITRSWT, then the HYDRO computations will include viscous effects; otherwise HYDRO computations are for a potential flow solution.

EXTERNAL REFERENCES:

BEGINØ
INPUTØ
HYDIN
SAPIN
HYDRO
NONSAP
CONGRG
OUTPST

CALLED BY:

Not applicable.

Subroutine FOILNN

FUNCTION:

FOILNN is a fairing cross-section, upper surface, library routine numbered "NN", where NN can range from Ø1 to 99. Files denoted "FOILØ1" through "FOILØ5" are currently implemented. These library routines will supply default surface coordinates when SHRTIN=.TRUE. (see DRIVER).

CALLING SEQUENCE:

Call FOILNN (X,Z,N).

COMMON BLOCKS:

None.

I/O UNITS:

None.

PRINCIPAL VARIABLES:

X,Z	arrays giving the fairing's upper surface coordinates, in inches (see subroutine DEFALT), on output.
N	number of fairing upper coordinate pairs on the output file.

EXTERNAL REFERENCES:

None.

CALLED BY:

DEFALT

FOIL ROUTINES CURRENTLY IMPLEMENTED:

FOILØ1	A typical fairing profile (measured from the actual cable sample given to BTS, Inc.)
FOILØ2	Fairing Model I, taken from: "Exp. Det'n. of Hydrodynamic Loading for Ten Cable Fairing Models", by R. Folb, DTNSRDC Rept. 4610, November, 1975.
FOILØ3	NACA 0020 section having a 3 inch chord
FOILØ4	NCS 0010 section, having a 3 inch chord
FOILØ5	Reserved for program expansion.

Subroutine HYDIN

FUNCTION:

HYDIN is an auxiliary routine which builds a complete HYDRO input file, based upon values for the control variables input through NAMELIST /DRV/. HYDIN is activated (only) when SHRTIN=.TRUE.

CALLING SEQUENCE:

Call HYDIN (IOUT, IPAPER, X,Z,N,V, ALPHA, ECHO, TITLE).

COMMON BLOCKS:

None.

I/O UNITS:

Unit 66	HYDRO input file
Unit 6	Printer output (SYSOUT=A)
Unit 22	Dummy.

PRINCIPAL VARIABLES:

IOUT	HYDRO input file number
IPAPER	output file, to echo the HYDRO input file being built
X,Z	arrays of fairing (upper surface) coordinates, expressed in inches (see DEFALT).
N	number of fairing upper surface coordinates
V	freestream velocity (ft/sec.)
ALPHA	fairing angle of attack (degrees)
ECHO	=.TRUE., produce an "echo" of the HYDRO input file
TITLE	80 character (run) title

EXTERNAL REFERENCES:

DEFALT	
DSQRT	FORTRAN double precision square root
DFLOAT	FORTRAN double precision floating point conversion.

CALLED BY:

DRIVER

Subroutine INPUTØ

FUNCTION:

INPUTØ over-rides the default values, assigned to HYDROSAP control variables (see BEGINØ), with control values read in through NAMELIST /DRV/.

CALLING SEQUENCE:

Call INPUTØ.

COMMON BLOCKS:

/REALØ/	/INTGR2/
/INTGRØ/	/LOGICØ/
/INTGR1/.	

I/O UNITS:

Unit 5
Unit 6.

PRINCIPAL VARIABLES:

Principal variables are read in, via namelist format, through /DRV/. A full description of the control variable functions and defaults is included in the discussion of NAMELIST /DRV/. We include here only a list of the relevant variable names:

NAMELIST /DRV/
INTORD, INTORX, IPANEL, IPAPER, ISMTH, ITRSWT, IWRTØ, IWRT1, LOOPMX, MESHC, MESHT, N, NSTEPS,
CORE, DEBUG, ECHO, HYDSIM, POST, SAPSIM, SHRTIN, SKIN, TAIL, TPRINT,
ALPHA, ECORE, ESKIN, ETAIL, PCORE, PSKIN, PTAIL, PZERO, RHO, TOL,
TSKIN, Y1CORE, Y2CORE.

EXTERNAL REFERENCES:

None.

CALLED BY:

DRIVER

AD-A071 202 BUSINESS AND TECHNOLOGICAL SYSTEMS INC SEABROOK MD F/G 13/6
PROGRAM DEVELOPMENT TO STUDY FAIRED TOWLINES.(U)
JAN 79 J B EADES, V MAJER N00014-78-C-0410
UNCLASSIFIED BTS-IR-79-74 ONR-CR298-003-1 NL

2 OF 2
AD
A071202

END
DATE
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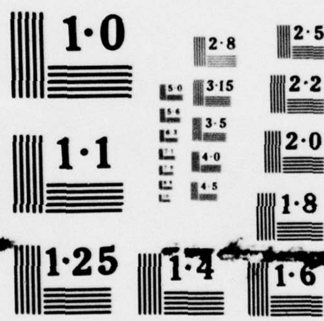
8-79
DDC



NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Subroutine OUTPST

FUNCTION:

OUTPST writes the pressure distribution and shape data to output unit 88; there it can be ready by a graphics post-processor -- such as program HSGRAF -- in a subsequent job or job step.

CALLING SEQUENCE:

OUTPST.

COMMON BLOCKS:

/INTGRØ/	/SURFCE/
/REALØ/	/ARRAYØ/
/LOGICØ/	/ARRAY1/

I/O UNITS:

Unit 88 output.

PRINCIPAL VARIABLES:

ZTITLE(20)	REAL*4 character array for (run) title
HYDSIM, SAPSIM, SKIN, CORE, TAIL	HYDROSAP control variables, see discussion of NAMELIST /DRV/

EXTERNAL REFERENCES:

None.

CALLED BY:

DRIVER

Subroutine SAPIN

FUNCTION:

SAPIN is an auxiliary routine which builds a complete NONSAP input file based upon values assigned to the control variables (input) through NAMELIST /DRV/. SAPIN is activated if SHRTIN=.TRUE.

CALLING SEQUENCE:

```
Call SAPIN (IOUT, IPAPER, Y,Z,N, ECHO, TITLE, NSTEPS, SKIN, CORE, TAIL,
            MESHC, MESHT, ESKIN, ECORE, ETAIL, TSKIN, PCORE, PTAIL,
            PSKIN, Y1CORE, Y2CORE).
```

COMMON BLOCKS:

None.

I/O Units:

Unit 55	NONSAP input unit
Unit 6	Printer output (SYSOUT=A)
Unit 22	Dummy

PRINCIPAL VARIABLES:

IOUT	NONSAP input file number
IPAPER	output unit number for NONSAP input file echo
Y,Z	coordinate arrays describing a fairing upper surface
N	number of upper surface coordinate pairs
ECHO	=.TRUE., echos the input deck, written to unit IPAPER
TITLE (10)	REAL*8, 80 character (run) title.

NSTEPS SKIN CORE TAIL MESHC MESHT ESKIN ECORE ETAIL TSKIN PCORE PTAIL PSKIN Y1CORE Y2CORE	HYDROSAP control variables. See the discussion of NAMELIST /DRV/ for details.

EXTERNAL REFERENCES:

None.

CALLED BY:

DRIVER

Subroutine TAINT

FUNCTION:

TAINT is a general-purpose table lookup and interpolation algorithm.

SOURCE AND AUTHOR:

AMES Research Center (anon.)

CALLING SEQUENCE:

Call TAINT (XTAB, FTAB, X, FX, N, K, NER, MON).

COMMON BLOCKS:

None.

I/O UNITS:

Unit 6   Printer output (SYSOUT=A)

PRINCIPAL VARIABLES:

XTAB(1)	array of x-coordinates (input)
FTAB(1)	array of function values (input)
X	x-coordinate at which function value is desired (input)
FX	interpolated function value (output)
N	number of points in XTAB, FTAB (input)
K	interpolation order, $k = \max(N,9)$
NER	error condition flag
MON	MON≠0: XTAB, FTAB unchanged from previous call
	MON=0: New XTAB, FTAB arrays.

EXTERNAL REFERENCES:

None.

CALLED BY:

HYDRO, SAPIN, LOADER

Subroutine LOADER

FUNCTION:

LOADER controls the computation of a set of consistent loads which are to be applied to the foil at the NONSAP fairing surface nodes. These loads are based on the "computed pressure distribution" from HYDRO.

CALLING SEQUENCE:

Call LOADER (NOD, IDIRN, NCUR, FAC, NLOAD, P, XCT, ZCT, NXUPTH, NXLOTH).

COMMON BLOCKS:

/INTGRØ/
/LOGICØ/
/SURFCE/

I/O UNITS:

None.

PRINCIPAL VARIABLES:

NOD(1)	NOD(I) = node to which the I^{th} nodal load is applied
IDIRN(1)	IDIRN(I) = direction (2~y, 3~z) for the I^{th} nodal load
NCUR(1)	NCUR(I) = time function (non-dimensional load profile) to which nodal load I is referred
FAC(1)	FAC(I) = value of nodal load I
NLOAD	total number of nodal loads being applied
P(1)	HYDRO-computed pressure distribution array (packed)
XCT(1), ZCT(1)	HYDRO surface coordinate arrays (packed)
NXUPTH(7,2), NXLOTH(7,2)	upper and lower surface coordinate index storage (needed to unpack XCT, ZCT, P)
YUP(41),ZUP(41)	NONSAP upper surface coordinates
YLO(41),ZLO(41)	NONSAP lower surface coordinates

EXTERNAL REFERENCES

TAINT
NDLLDS

CALLED BY:

LOADS (in NONSAP module).

Subroutine NDLLDS

FUNCTION:

NDLLDS determines the consistent set of nodal loads from the NONSAP surface geometry and input pressure distribution.

CALLING SEQUENCE:

Call NDLLDS (Y,Z,P,PY,PZ,N)

COMMON BLOCKS:

None

I/O UNITS:

None

PRINCIPAL VARIABLES:

N	number of NONSAP surface nodes
Y,Z	surface coordinate arrays
P	pressure distribution array
PY,PZ	consistent nodal load arrays

EXTERNAL REFERENCES:

None

CALLED BY:

LOADER (in NONSAP module).

Subroutine CPTOP

FUNCTION:

CPTOP converts the non-dimensional pressure coefficients into pressures (for loads purposes).

CALLING SEQUENCE:

Call CPTOP (CP, PØ, RHO, V, P)

COMMON BLOCKS:

None

I/O UNITS:

None

PRINCIPAL VARIABLES:

CP	pressure coefficient (input)
PØ	static pressure (psi) (input)
RHO	fluid density (slugs/ft^3) (input)
V	fluid freestream velocity (ft/sec)
P	stream dynamic pressure (psi) (output)

EXTERNAL REFERENCES:

NONE

CALLED BY:

HYDRO

Subroutine WRT14

FUNCTION:

WRT14 is a subprogram used to write the HYDROSAP checkpoint/restart tape, FT14FØØ1. WRT14 concatenates the four NONSAP restart tapes onto one tape; also, it adds to the tape the HYDRO checkpoint/restart data.

CALLING SEQUENCE:

Call WRT14 (TPRINT, TIME, IPAPER, ITER, XCT, ZCT, P, NXUPTH, NXLOTH)

COMMON BLOCKS:

None

I/O UNITS:

FT14FØØ1	HYDROSAP restart tape
FTØ4FØØ1	NONSAP restart tapes
FTØ8FØØ1	
FTØ9FØØ1	
FT13FØØ1	

PRINCIPAL VARIABLES:

TPRINT	terminal print control flag (logical)
TIME	time, at the checkpoint
IPAPER	printer output unit number
ITER	HYDROSAP iteration count at checkpoint
XCT	HYDRO data for checkpoint
ZCT	
P	
NXUPTH	
NXLOTH	

EXTERNAL REFERENCES:

TPSCAN	routine to scan unformatted tapes for number of records and record length
ERRSET	IBM utility sub-program to suppress error messages

CALLED BY:

NONSAP

Subroutine TPSCAN

FUNCTION:

TPSCAN is a program used to determine the number of 4-byte words per record, and the number of logical records, on an unformatted I/O unit.

CALLING SEQUENCE:

Call TPSCAN (IUNIT, NREC, NWORDS, IER)

COMMON BLOCKS:

None

I/O UNITS:

Tape IUNIT, determined by calling sequence

PRINCIPAL VARIABLES:

IUNIT	unit number being scanned
NREC	number of records on IUNIT
NWORDS(1ØØØ)	an array containing the number of 4-byte words on each record, up to a maximum of 1000 records
IER	error return code

EXTERNAL REFERENCES:

None

CALLED BY:

WRT14

Subroutine READ14

FUNCTION:

READ14 is a program to unload the HYDROSAP restart tape (FT14FØØ); READ14 is called when RESTRT=.TRUE.

CALLING SEQUENCE:

Call READ14 (TPRINT, TSTART, ITER, XCT, ZCT, P, NXUPTH, NXLOTH, IER)

COMMON BLOCKS:

None

I/O UNITS:

FT14FØØ1	HYDROSAP restart tape
FTØ4FØØ1	NONSAP restart tapes
FTØ8FØØ1	
FTØ9FØØ1	
FT13FØØ1	

PRINCIPAL VARIABLES:

IER	error return code
TSTART	time at restart
TPRINT	logical terminal print control flag
ITER	HYDROSAP iteration count at restart
XCT, ZCT, P, NXUPTH, NXLOTH	HYDRO data for restart

EXTERNAL REFERENCES:

None

CALLED BY:

NONSPI

APPENDIX C

HYDROSAP IBM Job Control Language

HYDROSAP IBM Job Control Language

The job control statements necessary to run the HYDROSAP system on the NASA/Goddard Space Flight Center's IBM 360/91 machine, are discussed in this appendix. These control statements are, of course, machine-dependent.

A typical job consists of five steps: (1) jobcard, (2) system input stream definition, (3) link-overlay, (4) execution, and (5) user notification.

Jobcard

The jobcard contains the job name, accounting information, and time estimates for the run. Changes are normally made only to the job name and time estimates:

Example:

```
//YC2VMH30 JOB (            ,T,AAAAAA,H00H01),006,NOTIFY=YC2VM
```

jobname account number time estimate

System Input Stream Definition

The SYSIN jobstep defines the contents of the system input stream, FORTRAN unit FTØ5FØØ1. The input stream contains card images of the input to be read by HYDROSAP. The contents of this file are altered for each new run, as described in section 2.4.

Example:

```
// EXEC SYSIN
//SYSIN DD *
 NACA 0020 FAIRING CROSS SECTION:  SAMPLE ANALYSIS
$DRV
 SHRTIN=T,IPRINT=5,ITRSWT=1,LOOPMX=15,MESHC=11,MESHT=3,
 N=-3,NSTEPS=20,CORE=T,DEBUG=T,SKIN=T,TAIL=T,TPRINT=T,
 TSTART=0.D0,ALPHA=8.D0,ECORE=1.D06,ESKIN=2.D03,ETAIL=1.D05,
 PCORE=.3D0,PTAIL=.3D0,PSKIN=.3D0,TOL=1.D-3,TSKIN=5.D-02,
 VFRSTR=22.D0,Y1CORE=0.D0,Y2CORE=.75D0,POST=F,CHKPNT=T,
 IPANEL=0,ISMTH=4
$END
```

Link-Overlay

The LINK jobstep assembles and link edits the various program segments, constituting the HYDROSAP system, into a single executable load module, based on the linkage editor commands which define the overlay structure. Object modules for the root segment and two overlay segments are stored in load libraries ZOFIMDRV, ZOFIMHYD, and ZOFIMFEL, respectively. These control statements are normally not altered.

Example:

```
//LINK EXEC PGM=IEWL,PARM='LIST,MAP,LET,OVLY,SIZE=(240K,72K)',
//             REGION=250K,COND=(4,LT)
//SYSPRINT DD SYSOUT=A,DCB=BLKSIZE=3509,SPACE=(CYL,(3,1),RLSE)
//*SYSPRINT DD SYSOUT=A,DCB=BLKSIZE=3509
//SYSLMOD DD UNIT=2314,DISP=(NEW,PASS),DSN=&&LODMOD(GSFC),
//              SPACE=(6144,(40,20,1),,,ROUND)
//SYSUT1 DD UNIT=2314,SPACE=(6144,(40,20,1),,,ROUND)
//SYSLIB DD DSN=SYS1.DUMMY,DISP=SHR
//        DD DSN=SYS1.DUMMY,DISP=SHR
//        DD DSN=SYS1.FORTLIB,DISP=SHR
//        DD DSN=SYS2.FORTLIB,DISP=SHR
//        DD DSN=SYS1.PLILIB,DISP=SHR
//        DD DSN=SYS1.FORTSSP,DISP=SHR
//        DD DSN=SYS2.LOADLIB,DISP=SHR
//LIB     DD DSN=SYS2.LOADLIB,DISP=SHR
//SYSLIN DD *
 INCLUDE LIB(ZOFIMDRV)
 INCLUDE LIB(ZOFIMHYD)
 INCLUDE LIB(ZOFIMFEL)
  INSERT MAIN,TAINT,CONVRG,OUTPST
  INSERT REAL0,INTGR0,LOGIC0,INTGR1,INTGR2,SURFCE,LOGICA,ARRAY0
 OVERLAY ONE
  INSERT HYDIN,SAPIN,DEFALT,FOIL01,FOIL02,FOIL03,FOIL04,FOIL05
  INSERT BEGIN0,INPUT0
 OVERLAY ONE
  INSERT HYDRO,INTER
  INSERT CPTOP
  INSERT ALL,ALPMCH,BLAYER,BLK40,CFALL,CF5,CNFLTR,GEOMT,HLM4
  INSERT LOAD,POTFLW,POTWK,TEMP,THETAJ,TURBTR,VISCOS,WORK
 OVERLAY TWO
  INSERT AIRGM,READIT,PRTGM,GEOM,PRTCRD,TRANS,PANEL,CURV
  INSERT SMOCR,GAPA,CUBSPL,OVRLAP
 OVERLAY TWO
  INSERT POTFL,POTVL,KUTTA,DSTEQ,CAMBER,SMOOTH,THKVL,DELLER
  INSERT SIMSOL,SOURCE,COMPR
```

(Continued)

```
OVERLAY TWO
 INSERT BDLYR,DERV,LAMBL,PROOT,BLTRAN,TURBL,CONFBL,DLIM
 INSERT CONF5,CONF7,CONF8
OVERLAY TWO
 INSERT LOADS0
OVERLAY ONE
 INSERT NONSAP,ERROR,ELCAL,ADDRES,ASSEM,LOADEF,COLSOL,EQUIT
 INSERT NEWDAV,WRITE,STRESS,COLHT,ADDBAN,ADDDI,ADDMA,ADDCM
 INSERT MULT,ELEMNT,STIME,TTIME,CAUCHY
 INSERT WRT14,TPSCAN
 INSERT EM,MTMD3D,VMISES,DRPRAG,DIMEL,THREED,TODIM,DISDER
 INSERT MATMOD,TAPEIG,NSAPI,ELGFLG,DAMPNG,PRCON,CRACK,NORMS
 INSERT TAPES,VAR,JUNK,LDA,CONST,EL,DIM,SOL,X00001,A
OVERLAY THREE
 INSERT NONSPI,OPCDEF,INPUT,LOADS,NODMAS,INITAL,LOADER,NDLLDS
 INSERT READ14
OVERLAY THREE
 INSERT TRUSS,RUSS,MATBAR
OVERLAY THREE
 INSERT TODMFE,TDFE,INITWA,MATRT2,QUADS,QUADM,DERIQ,FUNCT2
 INSERT MAXMIN,STSTL,POSINV,STSTN
OVERLAY FOUR
 INSERT ELT2D3,IVTMOD,VTMOD
OVERLAY FOUR
 INSERT ELT2D4,ICIMOD,CIMOD,DCRACK
OVERLAY FOUR
 INSERT ELT2D6,IELPAL,ELPAL,MIDEP
OVERLAY FOUR
 INSERT ELT2D7,IDRUCK,DRUCK,PRAGER
OVERLAY FOUR
 INSERT ELT2D8,MOONEY
OVERLAY FOUR
 INSERT ELT2D9,EL2D10,EL2D11,EL2D12
OVERLAY THREE
 INSERT THREDM,THDFE,MATWRT,INTWA3,QUADS3,QUADM3,DERIQ3,FUNCT
 INSERT STST3L,STST3N
OVERLAY FIVE
 INSERT ELT3D3,ICMOD3,CMOD3D
OVERLAY FIVE
 INSERT ELT3D5,ELT3D6
OVERLAY THREE
 INSERT FREQS,SECANT,MLTPLY,BANDET,PNORM,WRTFRQ,MAXAEX,READID
ENTRY MAIN
```

Execution:

The GO step initiates execution of the complete load module which was produced in the link step. The GO step JCL also defines the FORTRAN I/O

units which will be accessed by the program.

Example:

```
//GO EXEC PGM=*.LINK.SYSLMOD,REGION=390K,COND=(4,LT)
//GO.FT01F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR1
//GO.FT02F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR2
//GO.FT03F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR3
//GO.FT04F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR4
//GO.FT05F001 DD DDNAME=DATA5
//GO.FT06F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=7265)
//GO.FT07F001 DD DUMMY
//GO.FT08F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR2
//GO.FT09F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR3
//GO.FT10F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR4
//GO.FT11F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR1
//GO.FT12F001 DD SYSOUT=X,DCB=(RECFM=FB,LRECL=80,BLKSIZE=80)
//GO.FT13F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
// DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR1
//*GO.FT14F001 DD UNIT=2314,SPACE=(TRK,(60,60)),
//*DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),VOL=SER=M2SCR2
//GO.FT14F001 DD DSN=YC2VM.HS14.DATA,UNIT=2314,SPACE=(TRK,(20,20)),
// DISP=(NEW,PASS),DCB=(RECFM=VSB,LRECL=1284,BLKSIZE=2572),
// VOL=SER=M2SCR2
//GO.FT22F001 DD DUMMY
//GO.FT55F001 DD UNIT=2314,SPACE=(TRK,(20,20)),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200),VOL=SER=M2SCR2
//GO.FT66F001 DD UNIT=2314,SPACE=(TRK,(20,20)),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200),VOL=SER=M2SCR2
//*GO.FT88F001 DD UNIT=2314,SPACE=(TRK,(20,20)),
//*DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200),VOL=SER=M2SCR3
//GO.FT88F001 DD DSN=YC2VM.HS88.DATA,UNIT=2314,SPACE=(TRK,(20,20)),
// DISP=(NEW,PASS),DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200),VOL=SER=M2SCR3
//GO.DATA5 DD DSN=&&DATA5,DISP=(OLD,DELETE)
```

User Notification

The NOTIFY step is used to send a notification to the user's remote terminal that the program has completed execution. The system completion code for each job step is displayed.

Example:

```
// EXEC NOTIFYTS,ID=YC2VM,MODE=ALL,MSG='HYDROSAP SAMPLE'
```

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